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TRACKING TEST TECHNIQUES FOR HANDLING QUALITIES EVALUATION

THOMAS R. TWISDALE
Project Engineer

DAVID L. FRANKLIN
Capt, USAF
Project Engineer

D D C

May 1975

Final Report

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Prepared by:

THOMAS R. TWISDALE
Project Engineer

DAVID L. FRANKLIN
Captain, USAF
Project Engineer

This report has been reviewed and is approved for publication:
13 May 1975

JAMES W. WOOD
Colonel, USAF
Deputy Commander for Operations

ROBERT A. RUSHWORTH
Brigadier General, USAF
Commander

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Flight tests were conducted and techniques were developed for evaluating the handling qualities of an aircraft using combat-oriented air-to-air tracking maneuvers. This technique involves precision tracking of a target aircraft through wind-up turn and constant angle of attack turn maneuvers. The gun camera film of these maneuvers was analyzed for characteristic pipper motion relative to the target and tracking errors in the longitudinal

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and lateral-directional axes. Correlation of these data with pilot comments provides a means of evaluating the acceptability of aircraft stability and handling qualities in the maneuver environment for which the aircraft was designed. The TWeaD II F-4, which incorporated a variable gain control augmentation system (CAS), was used in the flight development of these tracking test techniques. Tracking test techniques proved to be a powerful tool for optimizing the TWeaD II flight control system in an in-flight environment using mission-oriented tracking tasks.

SUMMARY

Flight tests were conducted and techniques ~~were~~ developed for evaluating the handling qualities of an aircraft using combat-oriented air-to-air tracking maneuvers. This technique involves precision tracking of a target aircraft through wind-up turn and constant angle of attack turn maneuvers. The gun camera film of these maneuvers was analyzed for characteristic pipper motion relative to the target and tracking errors in the longitudinal and lateral-directional axes. Correlation of these data with pilot comments provides a means of evaluating the acceptability of aircraft stability and handling qualities in the maneuver environment for which the aircraft was designed. The TWeaD II F-4, which incorporated a variable gain control augmentation system (CAS), was used in the flight development of these tracking test techniques. With the CAS, three levels of handling qualities, ranging from good to unaugmented (poor) were evaluated in pitch, roll, yaw, and the combination roll and yaw axes. These handling qualities levels were successfully correlated with pipper motion, tracking error, and pilot rating and comments to the extent that acceptable handling qualities were distinguished from unacceptable handling qualities, and deficiencies were discovered and isolated. Tracking test techniques proved to be a powerful tool for optimizing the TWeaD II flight control system in an in-flight environment, using mission-oriented tracking tasks.

PREFACE

The authors wish to acknowledge the contributions of those not otherwise mentioned in this report, and to express their appreciation for those contributions.

Mr. B. Lyle Schofield, Chief, Flight Test Technology Branch, AFFTC, was the Program Manager for the Tracking Test Techniques Flight Development Study. Mr. Schofield developed the study plan which resulted in the flight study reported herein, and contributed invaluable conceptual guidance and engineering assistance.

The contribution of the project test pilots, Lt Col Richard E. Lawyer, USAF, and Lt Col (then Maj) Cecil W. Powell, USAF, extended beyond test flying duties and included valuable engineering assistance and operational support.

Subsequent to the development study, tracking test techniques have been used with considerable success in several modern fighter type aircraft test and evaluation programs. Mr. Robert G. Hoey, Mr. Gerald L. Jones, Maj James A. Eggers, USAF, and Maj William F. Bryant, USAF, were responsible for implementing tracking test techniques in these programs and have accumulated a great deal of experience and expertise. Each of these gentlemen, and Mr. Thomas Sisk of NASA/FRC and Mr. Schofield, devoted a considerable amount of time to reviewing this report. Their many suggested changes have resulted in what the authors believe to be a much better report.

All too often the contribution of the secretaries remains publicly unproclaimed. Mrs. Dorothy M. Shaffer and Miss Mary Jane Gugliotte deserve recognition for their excellent work, and for the many hours of time they devoted to the numerous drafts and revisions of this report.

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INTRODUCTION

The importance of mission-oriented pilot-in-the-loop handling qualities has long been recognized by the flight test community. However, no suitable flight test methods have been available for evaluating closed-loop handling qualities. The only tool available for evaluating closed-loop system performance has been subjective pilot opinion, in the form of the Cooper-Harper rating scale (Reference 1). The development of additional techniques for evaluating pilot-in-the-loop handling qualities would be desirable, particularly if the evaluation techniques could be related to mission-oriented flight conditions.

The potential of identifying closed-loop handling qualities deficiencies using air-to-air tracking was first identified by Mr. Thomas Sisk of the NASA Flight Research Center in his AIAA Fighter Airplane Conference Paper (Reference 2) and NASA TM-2248 (Reference 3). This potential was also recognized by the Air Force Flight Test Center (AFFTC), and a study plan was initiated to develop detailed air-to-air and air-to-ground tracking techniques, and data handling, analysis, and presentation procedures. This report presents the results of a flight study conducted to develop these techniques.

Methods were developed to evaluate pilot-in-the-loop precision tracking handling qualities of fighter and attack aircraft early in the flight test program. The methods investigated involve pilot observation and commentary, and supportive analysis of gun camera film of relative pipper to target motion during precision air-to-air and air-to-ground tracking maneuvers.

The aircraft used in this study was the TWeaD II F-4C, S/N 63-7409, which incorporated a variable gain control augmentation system (CAS). This system permitted the evaluation of three handling qualities models ranging from good to poor in the pitch, roll, yaw and combination roll and yaw axes.

Appendix B of this report presents detailed procedural information on air-to-air tracking techniques. This information will be incorporated into a future edition of AFFTC Stability and Control Manual. Accordingly, appendix B reflects the accumulated AFFTC experience with tracking test techniques. This experience was gathered during the study documented in this report and during subsequent flight test programs of several modern fighter type aircraft.

Appendix D documents the computer program developed during the study documented in this report. Subsequently, other programs have been written and are also being used in analyzing and presenting tracking test techniques data.

It is very important not to confuse tracking test techniques with the operational tracking and gun firing techniques associated with an actual combat encounter. Tracking test techniques are a powerful tool for identifying and defining handling qualities deficiencies and optimizing flight control systems. These techniques were specifically developed to elicit engineering data which may be used to improve the handling characteristics of the airplane. In this respect it is

certainly expected that the results of tracking test techniques (a better handling airplane) will favorably impact the operational pilot's ability to control his aircraft during combat encounters. But it would be a mistake to assume that the data gathered using these techniques directly reflect such overall mission effectiveness parameters as the likelihood of a kill. The overall combat effectiveness of the airplane is a function of many considerations. Tracking test techniques provide a measure of that portion of mission effectiveness which is related to the pilot's ability to precisely control the aircraft attitude.

OBJECTIVES

There is an old saying that, "If an airplane looks right it will fly right." Whether justification of this relationship is metaphysical or substantial, it can be reasonably assumed that flying "right" means that the airplane possesses handling qualities which permit the pilot to regularly and efficiently accomplish the task at hand: tracking and shooting down another aircraft in the air, delivering a bomb on target, tracking a glide slope, etc. Clearly, for an air superiority aircraft or a ground support aircraft the task is to control the gunsight pipper with reference to the target until a weapons trajectory solution is completed and the weaponry is deployed. If the pilot is able to perform the task easily and repeatably he will say the airplane flies "right", and the chances are commensurately greater that he will hit the target. Conversely, if his aircraft exhibits objectionable oscillatory or divergent characteristics, or other handling qualities deficiencies, or requires an abnormally high skill or proficiency level, his chances of hitting the target are reduced, as is the mission effectiveness.

It is desirable to isolate and correct open-loop as well as closed-loop handling qualities deficiencies which reduce mission effectiveness as early as possible in the development, test, and evaluation of the aircraft. Flight test methods have long been available for measuring and evaluating open-loop response, but heretofore no such methods existed for evaluating closed-loop system performance. Since the mission effectiveness of fighter-bomber type aircraft is related to the difficulty experienced by the pilot in controlling the gunsight pipper relative to the target, it is not unexpected that an analysis of gun camera movies of relative pipper to target motion might prove instructive. This potential for identifying pilot-in-the-loop handling qualities problems by analyzing relative pipper to target motion was recognized by Mr. Thomas Sisk, and was confirmed by this study.

The objectives of the tracking test techniques studies were: (1) to investigate flight test methods for evaluating pilot-in-the-loop handling qualities characteristics; (2) to substantiate air-to-air tracking as a viable pilot-in-the-loop test procedure; (3) to investigate the potential for using airto-ground tracking to identify handling qualities deficiencies associated with the ground support mission; (4) to develop and establish detailed test maneuvers and procedures for use in the flight test investigation of mission-oriented

flying qualities; and (5) to define data analysis and presentation procedures.

Fallout from these objectives include a uniquely effective technique for optimizing flight control systems and a potential technique for defining the open-loop frequency response characteristics of the airframe/control system combination using closed-loop tasks (Reference 4).

To demonstrate the usefulness of tracking test techniques, it was necessary to show that at least two levels of stability and handling qualities could be observed by correlating pilot qualitative comments with an analysis of tracking film. This objective was facilitated by the TWeaD II airplane, F-4C S/N 63-7409, which incorporated a variable gain CAS. With this aircraft, three levels of stability and handling qualities were evaluated in pitch, roll, yaw, and the combination roll and yaw axes. Briefly, these were "good" handling qualities (corresponding to the control augmentation system gains developed in the TWeaD II program, Reference 3), "degraded" handling qualities (corresponding to non-optimized gains), and handling qualities corresponding to those of the basic F-4 without dampers (CAS disengaged). These three levels provided an opportunity to analyze characteristics ranging from well coordinated and uniform handling qualities to handling qualities characterized by high adverse yaw at higher angles of attack stick force reversal, "dig-in", etc. The pilot's Cooper-Harper rating of these handling qualities levels ranged from fair to major deficiencies requiring improvement (3 to 7 on the Cooper-Harper scale). For a more detailed explanation of the characteristics associated with the stability levels see appendix A.

AIR-TO-AIR TRACKING TEST TECHNIQUES

The objective of the tracking test techniques is to quickly uncover closed-loop stability and handling qualities problems and anomalies over a large range of flight conditions while performing mission-oriented tasks. The approach taken was to develop a set of maneuvers which would first rapidly scan a broad spectrum of flight conditions for handling qualities deficiencies and then permit examination of the isolated defiencies more thoroughly. In this respect, the tasks found most useful for an air-to-air tracking analysis were wind-up tracking turns and constant angle of attack (constant-α) tracking turns. For this study, wind-up and constant-α tracking turns were performed at Mach numbers of .85 and 1.2, from 20,000 to 40,000 feet MSL, and at angles of attack up to 19 units.

The wind-up tracking turn consisted of tracking a target aircraft through a smooth wind-up turn (constant Mach number) of approximately 15-20 seconds duration. The constant-α tracking turn consisted of tracking a target aircraft through a constant-α and constant Mach number turn of 15 to 25 seconds duration or more. For both maneuvers the target range was usually 1000-1500 feet. These two maneuvers were selected because they permitted, respectively, a brief look at handling qualities over a large angle of attack range at constant Mach

number, and a more detailed look at specific angle of attack/Mach problem areas revealed in wind-up tracking. For example, during a wind-up tracking turn, it was discovered that accurate tracking was difficult at 16-19 units angle of attack and Mach = 0.80. A closer and more discerning look at this difficulty was obtained by tracking for 15 to 25 seconds at constant Mach = 0.80 and constant-α in the 16-19 units angle of attack region.

To evaluate the effect of large perturbations on the tracking task, rapid and essentially constant-g barrel-rolling reversals of the direction of turn were sometimes incorporated into the constant-α tracking turns. For example, a rolling reversal would be sandwiched between two constant-α tracking maneuvers. These reversals were performed at about combat break rate. The incorporation of reversals into constant-g turns permitted the tracking pilot to evaluate closed-loop system performance during his attempts to control and minimize the rapid, large amplitude pipper excursions associated with large stick deflection rolling maneuvers. Quantitative analysis of the pipper motion during reversals was found to be fruitless, but pilot comments were often useful.

A fixed gunsight with a low depression angle was used for these maneuvers. For this airplane, this insured that all pipper motion was a product of the pilot-airplane combination (without the extraneous reticle motion generated by computing gunsights) and that "pendulum" effect due to large gunsight depression angles was minimized. Generally, the pipper depression angle will depend on the airplane's roll axis (whether wind axis, body axis, or other).

Early in the program the tracking pilots were permitted to use the rudder pedals while tracking, but it was soon discovered that through determined and coordinated use of the rudder pedals the pilots were able to mask the poor handling qualities which would otherwise have been manifested in the motion of the pipper relative to the target. For this reason the pilots were thereafter required to perform the tracking tasks with their feet on the floor. This made many problems apparent when they might normally have been inobvious.

The fact that with considerable effort the pilots were able to effectively mask handling qualities problems by using the rudder pedals suggested a relationship between pilot workload and flying qualities. A measure of pilot workload was obtained during tracking maneuvers, however very little success accompanied the attempt to effectively relate that workload to tracking results and handling qualities. The measure of workload obtained was the absolute value of longitudinal and lateral stick force and rudder pedal force integrated over time. These forces were measured relative to the one g trim condition established prior to each maneuver.

It should be mentioned here that the pilot's learning curve appeared to play an initially important role in tracking test techniques. The experience of this study was that pilots who were unfamiliar with the test techniques or the flying qualities characteristics of the aircraft being tested required several familiarization maneuvers, or one or two familiarization flights before meaningful data and pilot comments could be obtained.

The experience of this program was that there were two primary requirements for a useful analysis of precision air-to-air tracking: (1) a time history of the aircraft response, in the form of gun camera film of the pipper motion relative to the target; and (2) the pilot's comments and Cooper-Harper rating for the tracking task. It was also desirable to acquire time histories of the input (e.g., stick forces), airplane response (e.g., normal acceleration, roll rate), and flight control system parameters (e.g., error signals).

The tracking pilot was found to be the most important factor in acquiring useful information. His primary task was to keep the gunsight pipper on a particular point on the target aircraft (precision aim point). He was requested to make a continuous and concerted effort to immediately return the pipper to the target on every occasion that it wandered away. This technique proved indispensable in analyzing the data. The pilot was asked not to permit the pipper to "float" near the target (a combat technique to get a tracking solution), nor to stabilize in order to facilitate returning it to the target. Doing so tended to mask the tendency for the airframe/control system to be excited by the pilot's efforts to precisely control the aircraft (pipper) motion.

The pilot of the target aircraft was also very important to the test results, since he was responsible for establishing and maintaining the maneuver flight path and test conditions. Deviations from these conditions often resulted in lost or less useful data.

In constant-α turns, particularly at lower angles of attack where buffet or other aerodynamic perturbations were not encountered, the airplane was initially excited by the pilot to insure that the system equilibrium was initially upset. This was accomplished by aligning the target on the outer ring of the reticle and then moving the pipper to the target as quickly and positively as possible.

Generally it proved very informative - and therefore very important - if the pilot provided a running commentary of his impressions during the tracking maneuver. The value of gathering impressions and comments cannot be overemphasized.

AIR-TO-GROUND TRACKING TEST TECHNIQUES

The technique explored in air-to-ground tracking was essentially similar to that used in air-to-air tracking. Two combat oriented air-to-ground maneuvers were used: a representative 30 degree dive bomb run and a 15 degree strafing run. Although insufficient data was gathered to determine the validity of these maneuvers as tracking test techniques, a brief description will perhaps benefit further development and test programs.

Dive Bombing: A modified 30 degree dive bomb pattern was flown, with roll-in at 10,000 feet MSL at 250 KIAS and "release" (end of tracking) at 450 KTAS and 4,000 feet MSL. A 30 degree rather than a 45 degree bomb run was selected because it offered slightly more available tracking time from roll-in to release. No external stores were

carried. Data was taken from roll-in through release. The ground target was aligned on the 60 mil ring of the reticle and then the pipper was moved to the target as rapidly as possible. As in air-to-air tracking a concerted and positive effort was exerted to keep the pipper on, or return it to, the ground target.

Originally the pilot was required to track with his feet off the rudder pedals, as in air-to-air tracking. But the greater gunsight depression angle (118 mils) and resultant pendulum effect plus the relatively short time available for acquiring the target, stabilizing on it, and tracking, indicated the critical requirement for good coordination of roll with yaw inputs. Tracking with any accuracy at all was extremely difficult without rudder inputs - a difficulty which was reflected in the poor data acquired. This problem was additionally exacerbated by turbulence and cross winds, which accentuated the short time available for stabilizing and tracking and the necessity of yaw inputs to coordinate roll. Accordingly, the pilot was subsequently permitted to use the rudder pedals for dive bombing tracking.

Strafing Runs: The strafing tracking runs were flown at about 400 KIAS with a 35 mil depression angle. The smaller depression angle reduced the pendulum effect so that the tracking could be performed with feet off the rudder pedals. Still, it was more difficult for the pilot to track a target on the ground than in the air.

EVALUATION OF TRACKING TEST TECHNIQUES DATA

Because of the combat oriented tracking tasks involved, it was anticipated that the relationship between tracking test techniques data and overall combat effectiveness might be confused or misinterpreted. In order to preclude any misinterpretation, three points need to be made. First, that the maneuvers and piloting techniques implemented in tracking test techniques are not, and were not intended to be, the same as real-world operational or combat maneuvers and techniques. Second, that there is no direct relationship between the amount of time the pipper spends on the target using tracking test techiques and the amount of time it can be expected to spend on the target during an actual combat encounter. Third, that the overall combat effectiveness of an airplane is a function of many considerations. Tracking test techniques provide a measure of that portion of mission effectiveness which is related to the pilot's ability to precisely control aircraft attitude.

The maneuvers and piloting techniques described in this report are oriented towards, but are clearly different from those associated with operational combat tracking and gunnery in numerous respects. For example, the lead computing gunsights used operationally significantly alter pipper motion characteristics and thus pilot response. An actual gun-firing pass requires only a few seconds of on-target tracking, rather than 20-25 seconds. Depending on airplane characteristics, the pilot will probably allow the pipper to float near the target at times, rather than aggressively attempting to drive it back to the target as required in tracking test techniques. The pilot may use the rudder pedals during actual combat encounters, but he may

not use them in tracking test techniques. And of course, an enemy target aircraft will be maneuvering violently rather than flying a predetermined and carefully controlled flight path.

The gun camera film of pipper motion relative to the target during the tracking test maneuver is primarily useful as a supplementary record and physical measure of what the pilot observed. Taken by itself, pipper motion analysis has not been established as a precise quantitative indication of handling qualities or mission effectiveness. Its value is as a supplement to the pilot's comments and observations, and as a general indicator of progress in flight control system optimization. Pipper motion, or pipper error analysis is secondary, i.e. supportive data and must not be mistaken for a quantitative index of flying qualities or overall mission effectiveness.

RESULTS OF AIR-TO-AIR TRACKING DATA ANALYSIS

The analysis of pilot ratings and comments and gun camera film of tracking maneuvers provided a rapid means of uncovering stability and handling qualities problems in the maneuver environment for which the aircraft was designed. Using this technique, it was possible to quickly isolate those portions of the flight envelope where the aircraft was deficient so that if necessary a more detailed investigation of the causal factors could be made using conventional flight test procedures. This technique also demonstrated, in a practical manner, the impact on mission effectiveness when the pilot's ability to precisely control the aircraft attitude was reduced because of unresolved stability and handling qualities problems. (R 1)[1]

The air-to-air tracking data was acquired for basically two flight conditions: subsonic and supersonic. The subsonic data was gathered at a true Mach number of .85, an altitude of 20,000 feet, and a forward cg (clean airplane except for forward AIM 7's). Mach number was held essentially constant throughout the tracking test (altitude was sacrificed when necessary to keep the Mach number up).

The supersonic data was gathered at a true Mach number of 1.2, an altitude of 35,000 or 40,000 feet, and a forward cg (clean airplane except for forward AIM 7's). An attempt was made to hold Mach number constant by sacrificing altitude (6,000 to 8,000 feet in a wind-up turn), but at higher angles of attack the Mach number inexorably bled to subsonic values fairly rapidly. Only a limited amount of supersonic data was gathered.

The acquisition and presentation of data for analysis were centered around the gun camera film of the tracking maneuver. The film was scored, or read for relative position of the pipper to the target (x and y, or azimuth and elevation displacements from the precision aim

[1] Numerals preceded by an R within parentheses at the end of a paragraph corresponds to the recommendation numbers tabulated in the conclusions and Recommendations section of this report.

point) over the duration of the tracking. These data were used by the Tracking Test Techniques Plotting Program (appendix D) to compute and plot four (or five if specified) presentations:

1. A trace of pipper motion relative to the gunsight longitudinal (elevation) and lateral (azimuth) axes.

2. Longitudinal (elevation), lateral (azimuth), and total root mean square (RMS) error versus angle of attack (and g if specified).

3. Time histories of longitudinal (elevation), lateral (azimuth), and total error.

4. Percentage of the total tracking time that the pipper was within a given error range.

A detailed description of the tracking test techniques plotting program, with examples of output and plots, is presented in appendix E.

Pipper Motion: The plot of pipper position relative to the target (figure 1A) is a time history of the pipper's motion about the target in azimuth and elevation. The point at which data scoring began is denoted by an asterisk and the direction of motion is chronicled by periodic arrowheads. (The initial perturbation technique was not scored, i.e. scoring did not begin until the pipper had moved into the vicinity of the target.) This trace was primarily useful in identifying the pronounced characteristic motion associated with certain stability and handling qualities problems; e.g., the characteristic saddle-shaped or figure-eight motion associated with adverse yaw or wing rock.

RMS Error: The RMS error plots (figures 1B and 1C) presented RMS errors for whatever g's and angles of attack were specified (appendix D). RMS errors were computed for successive intervals of two units angle of attack or one g, from the minimum to the maximum value encountered during the maneuver. The computed RMS errors for each interval were presented at the mean value of angle of attack or g for that interval. The usefulness of this plot, taken by itself, was limited and can be misleading. Table I presents the RMS errors and pilot rating for each constant-α tracking maneuver performed and average values for all 10 unit and 14 to 16 unit turns broken down by stability level in each axis. It is apparent that while a general trend can be inferred from this data, indicating that RMS errors could be considered rough indications of stability and handling qualities problems, they could not be considered conclusively indicative of particular gradations of stability and handling qualities. However, it is equally apparent that RMS error could be used as a measure of the gross deterioration of stability and handling qualities as flight conditions became more severe; i.e., at higher angles of attack where the airplane experienced wing rock, buffet, and stick force reversal and lightening.

Pipper Error Time Histories - Azimuth, Elevation and Total: The time histories of pipper motion (or error) in elevation (longitudinal) and azimuth (lateral-directional) (figure 1D) were conclusive in establishing the difference between acceptable and unacceptable handling qualities (as defined by the pilots' comments and Cooper-Harper

ratings encountered during this study) as well as in establishing gradations of handling qualities. A comparative analysis of the characteristic pipper motion of three levels of stability is presented in figures 2 and 3. From these figures it can be seen that each level of stability had a characteristic motion that distinguished it from the others.

These motions show that the good aircraft responded immediately to the pilot input; the degraded aircraft responded, but more slowly, and the unaugmented aircraft seemed to respond more to the natural frequency of the airplane than to any pilot input. The important point however, is that nearly all the tracking runs for a particular level of stability had a characteristic motion. This characteristic pipper motion suggested the possibility of analyzing pilot input (stick force) and aircraft response (pipper motion) to define airframe/control system transfer function and frequency response characteristics (Reference 4).

Percentage Tracking Time vs Error: It was expected that another way to evaluate handling qualities of a constant-α maneuver would be to see what percentage of the total tracking time the pipper spent within a given error range. For three different stability levels (good, degraded, and unaugmented), it was expected that the best level would have a high percentage of tracking time within a lower error range and the worst level would have a lower percentage of tracking time within the same error range (figure 1E). Figures 4 through 11 show that the three different stability levels (good, degraded, and unaugmented) generally followed this expected trend for a given axis or axes combination. For example, figure 4 shows that the percentage of tracking time the pipper spent within a 4 mil azimuth band of the pipper was progressively reduced as the yaw CAS was changed from the good to the degraded to the unaugmented configuation. This trend was visible in pitch and in combination roll and yaw as well. The trend was not apparent in roll however, where the good, degraded, and unaugmented tracking time versus error bands are essentially coincident (figure 5). This is believed to be because the gunsight depression angle was very close to the aircraft roll axis. If the depression angle were larger the resulting pendulum affect might have caused the good, degraded, and disengaged bands to exhibit the same trend as figures 4 and 6-11.

The plot of percentage tracking time vs error proved to be one of the more consistent and useful formats for presenting the data. The data acquired during this study was limited but appeared to indicate that as a rule of thumb, good handling qualities were characterized by approximately 60-80 percent tracking time within three-mil elevation and azimuth error bands at 10 units angle of attack (3 g's), and 30-60 percent tracking time at 14-16 units angle of attack (4-5 g's).

Pilot Ratings and Comments: Pilot ratings and comments were the most important aspect of tracking test techniques. In contrast with RMS pipper error, percentage tracking time vs error, or pipper time histories, the pilots were capable of consistently identifying even small gradations of stability and handling qualities. The pilots were the key in correlating cause and effect; i.e., in correlating the aircraft's motion, as manifested in the pipper traces, with stability,

GAC 10 Units				P Deg 10 Units				P Dis 10 Units				R Deg 10 Units			
Long Error	PR	L-D Error	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR
4.1	4	2.6		3.7	2.75	3.4		3.5	3	3.4		3.6		4.8	5
4.1	4	3.4		6.1	4	3.7		5.7	5	2.3		3.0	4	2.8	4
4.8	4	3.2		4.8	4	2.4		7.0	4	4.4		2.7	5	2.0	3
4.2	5	2.5	3	5.4	4	1.6		5.7	5	3.0		4.0	3	4.6	3.5
3.0	4	2.6	3	4.4	4	4.8	5	4.7	4	6.1	4.5	3.7	5	3.5	5
3.3	4	3.0	3	8.4	5	4.2	3	6.7	4	3.8	3	3.8	5	3.5	5
2.8	4	3.6	2	9.4	6.5	3.7	4.5	5.9	3	4.1	3	3.9	5	3.5	5
4.8	4	7.4	2									3.4	5	3.4	5
4.5	4	4.8	4												
4.0	4.1	3.7	2.8	6.0	4.3	3.4	4.2	5.6	4.0	3.9		3.5	4.6	3.5	4.6

GAC 14-16 Units				P Deg 14-16 Units				P Dis 14-16 Units				R Deg 14-16 Units			
L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR
5.5	4	6.4	4	10.4	6	4.9	2	10.3	7	3.3	3	5.6	4	9.5	6
5.1	4	7.8		9.0	6	6.7	4.5	4.3	3	5.1	4	6.1	4.5	4.8	6
7.2		7.6						5.5		5.5					
4.7	2	4.2	2												
5.6	3.3	6.5	3	9.7	6	5.8	3.3	6.7	5	4.6	3.5	5.9	4.3	7.2	6

Table I--Pilot Ratings/Tracking Error

R Dis 10 Units				Y Deg 10 Units				Y Dis 10 Units				R&Y Deg 10 Units				R&Y Dis 10 Units			
L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR
3.5		4.1	5	7.5		7.5	6	4.0	6.5	5.8	7	4.8	5	7.0	5	4.8	5.	6.0	6
4.0	5	2.5	4	5.0	4	3.5	3	4.4	5	7.5	5	2.8	4	3.6	5	4.6	5	4.8	6
4.0	5.5	4.2	5	3.2		4.0	5	3.0		8.4	7	3.2	4.5	2.9	4	3.4	5	6.1	6
				3.6	5.5	6.0	5	3.2	5	8.5	7	3.6	6	5.0	6	4.2	6	4.6	8
												2.9	5	7.1	6	4.0	5	6.4	8
												4.4	4	3.4	5	5.3	4.5	8.0	7
3.8	5.3	3.6	4.7	4.8	4.8	5.3	4.8	3.7	5.5	7.6	6.5	3.6	4.8	4.8	5.2	4.4	5.1	6.0	6.8

R Dis 14-16 Units				Y Deg 14-16 Units				Y Dis 14-16 Units				R&Y Deg 14-16 Units				R&Y Dis 14-16 Units			
L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR	L E	PR	L-D E	PR
7.0	4	5.7	6	6.5	6	6.4	5	6.0	4	11.4	7	4.4	7	5.3	5.5	6.6	5.5	11.8	7
5.7	5.5	6.0	6.5	6.1	4	10.0	6.5	8.6	5	12.4	7	5.5		10.2		11.8	6	11.2	7
3.3	5	4.0	5	6.2	4	6.8	3	3.7	5	6.6	6	3.8	6	3.4	5	6.7	6	13.3	7
				3.7	5	4.1	3.5					6.0	5.5	4.0	6	5.5	3	4.1	4.5
																3.8	4	9.1	5.5
5.3	4.8	5.2	5.8	5.6	4.8	6.8	4.5	6.1	4.7	10.1	6.7	4.9	6.2	5.7	5.5	6.9	4.9	9.9	6.2

Table I (Continued)

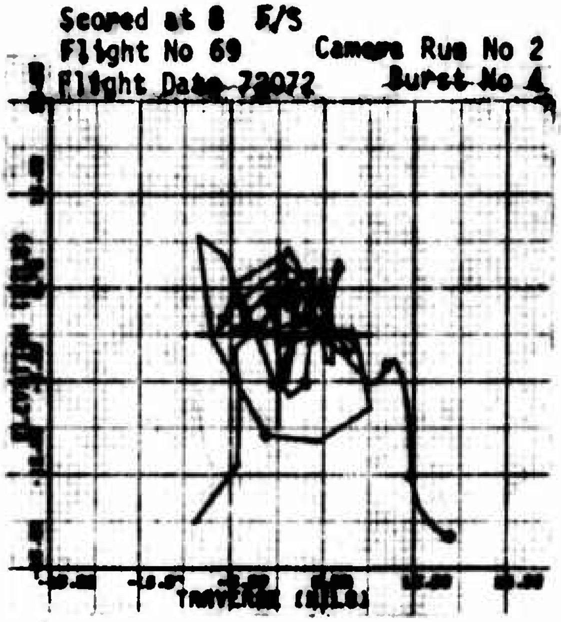


Figure 1A. Plot of Pipper Position versus Target

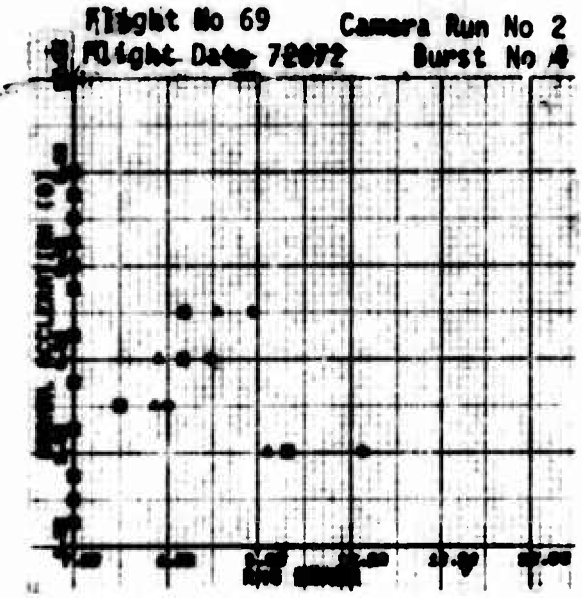


Figure 1B. Error versus

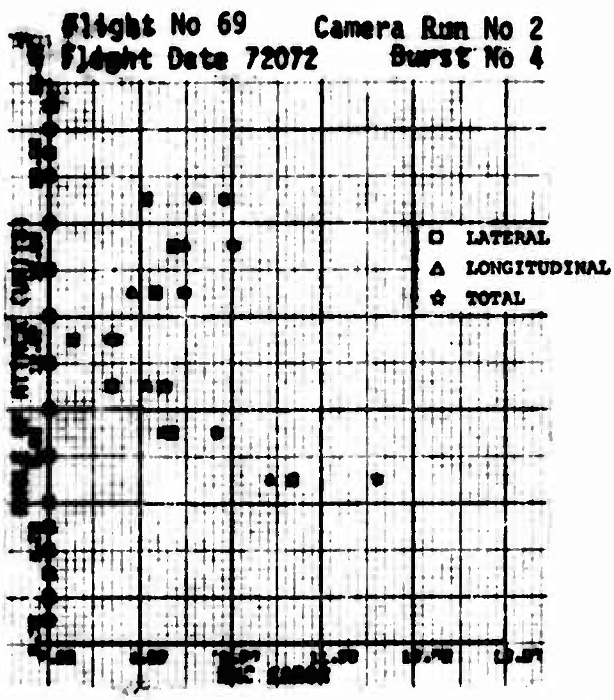


Figure 1C. Error versus Angle of Attack

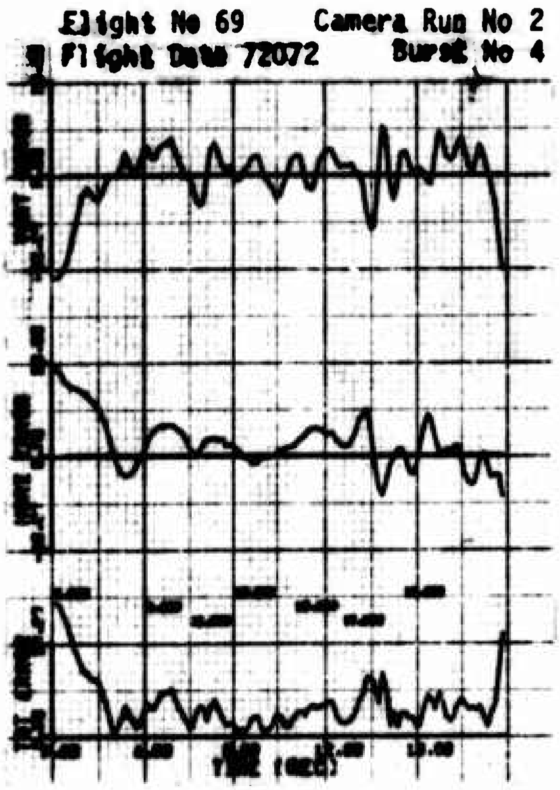


Figure 1D. [illegible] Time History

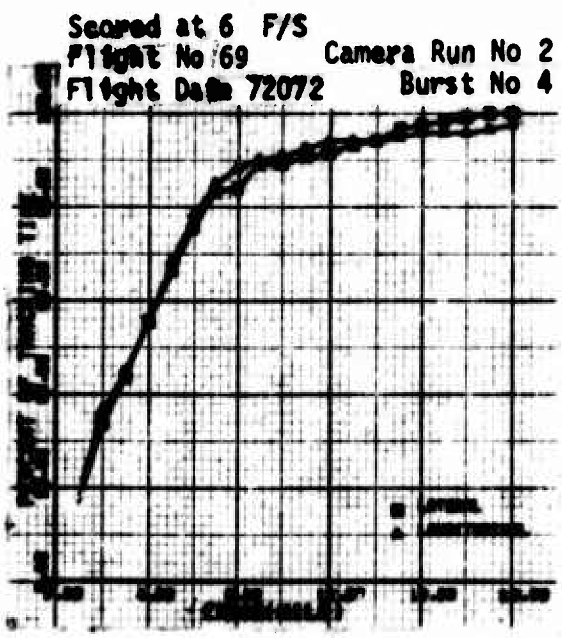


Figure 1E

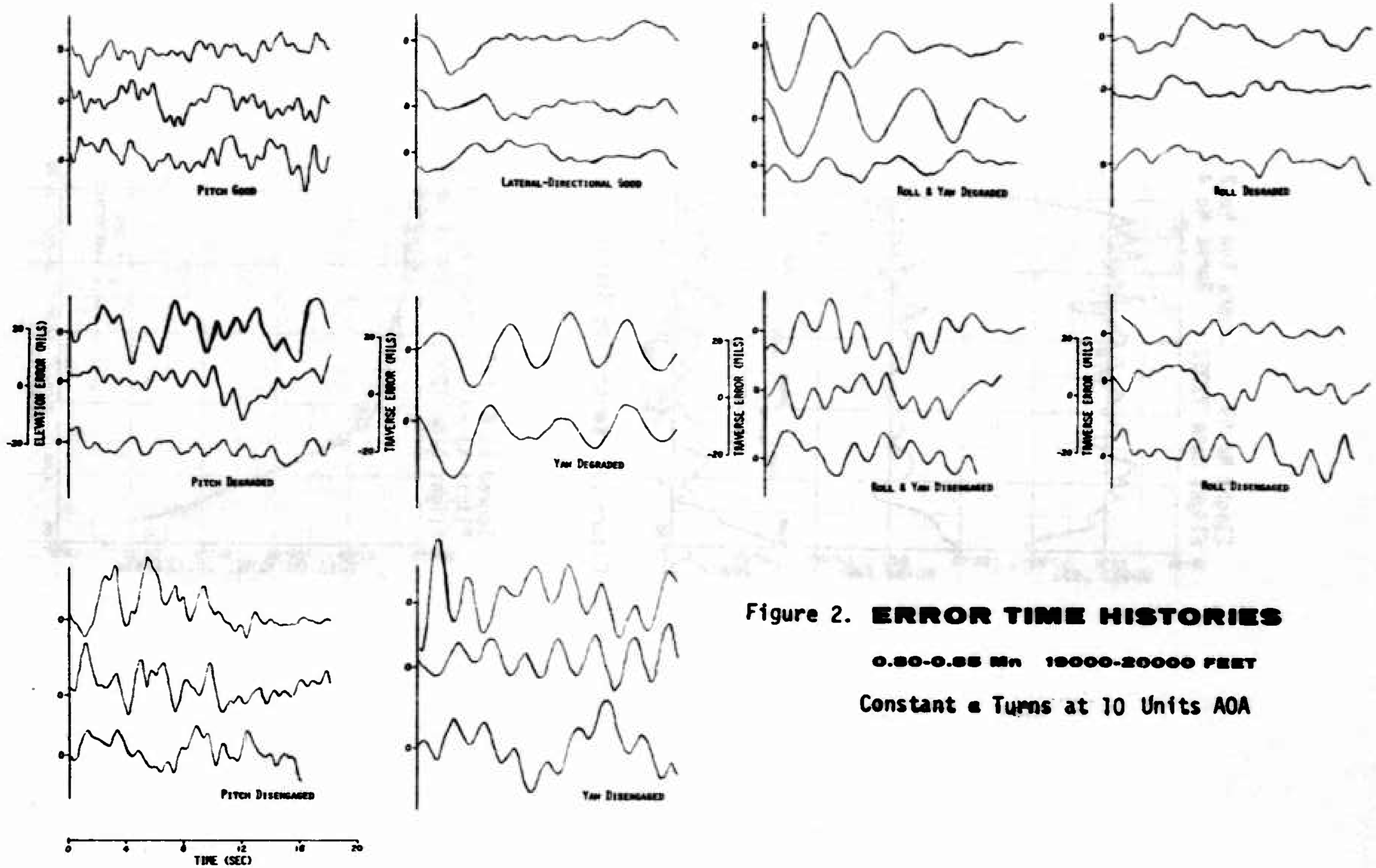


Figure 2. **ERROR TIME HISTORIES**

0.80-0.85 Mn 19000-20000 FEET

Constant a Turns at 10 Units AOA

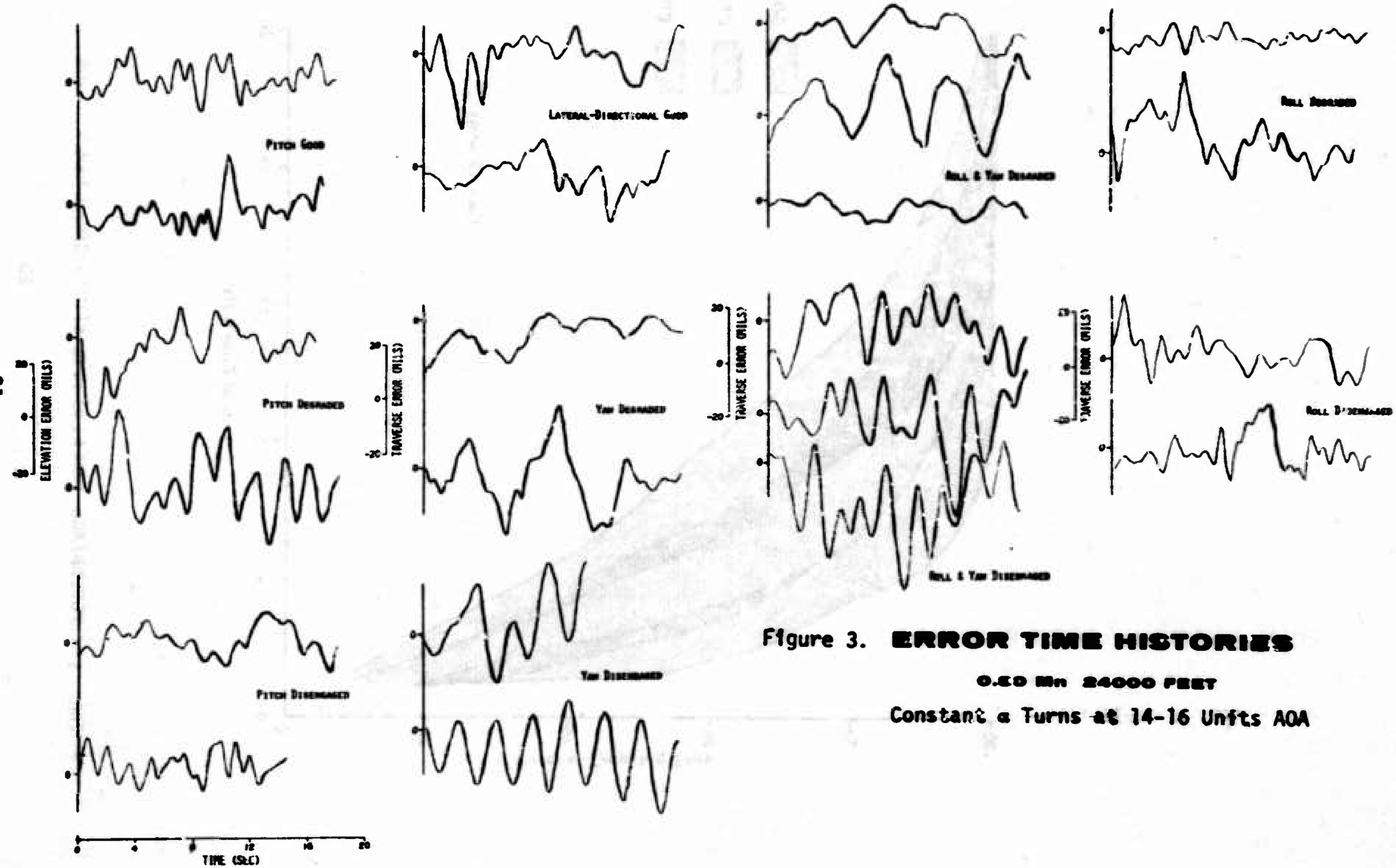


Figure 3. **ERROR TIME HISTORIES**

0.60 Mn 24000 FEET

Constant α Turns at 14-16 Units AOA

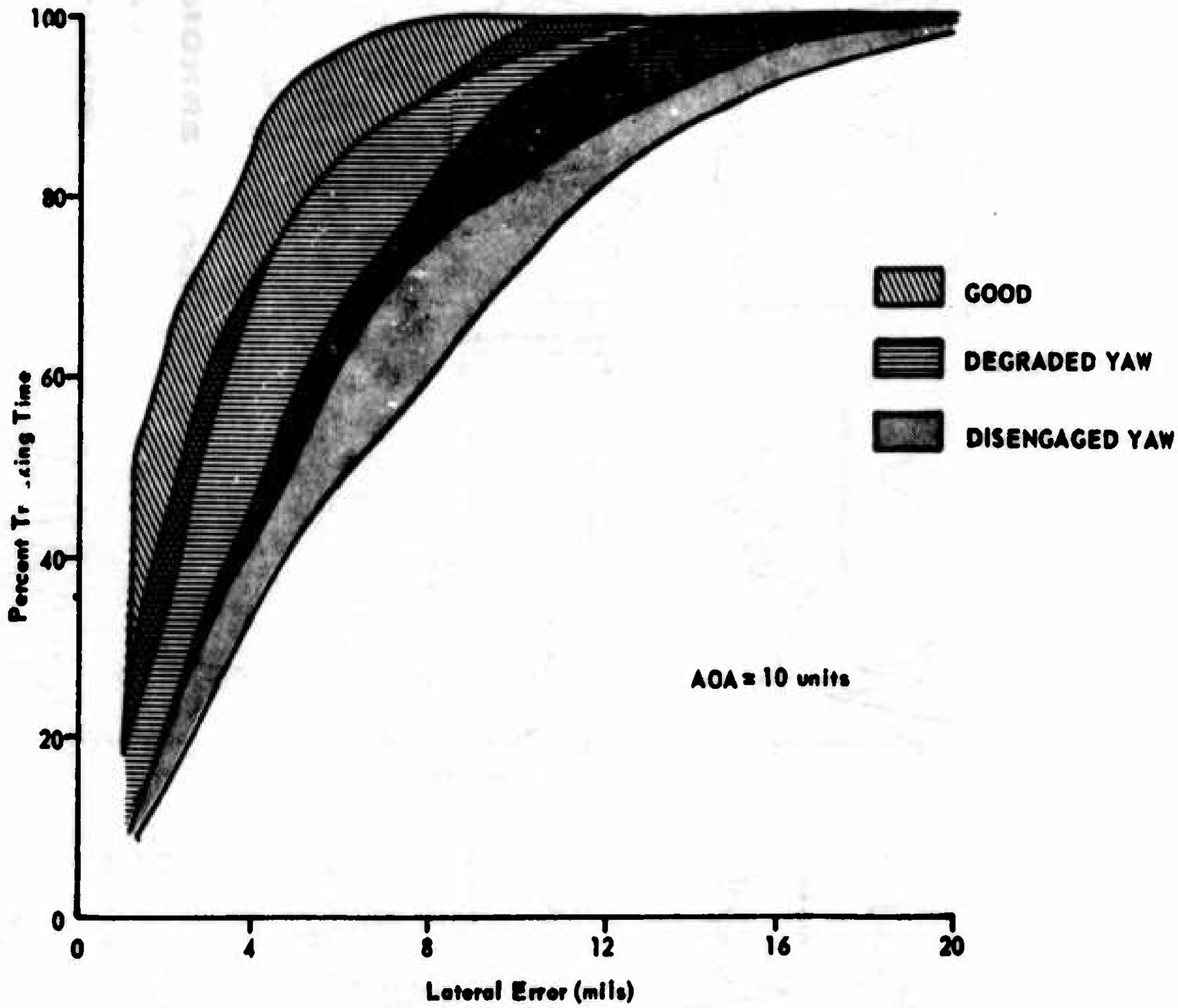


FIGURE 4 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

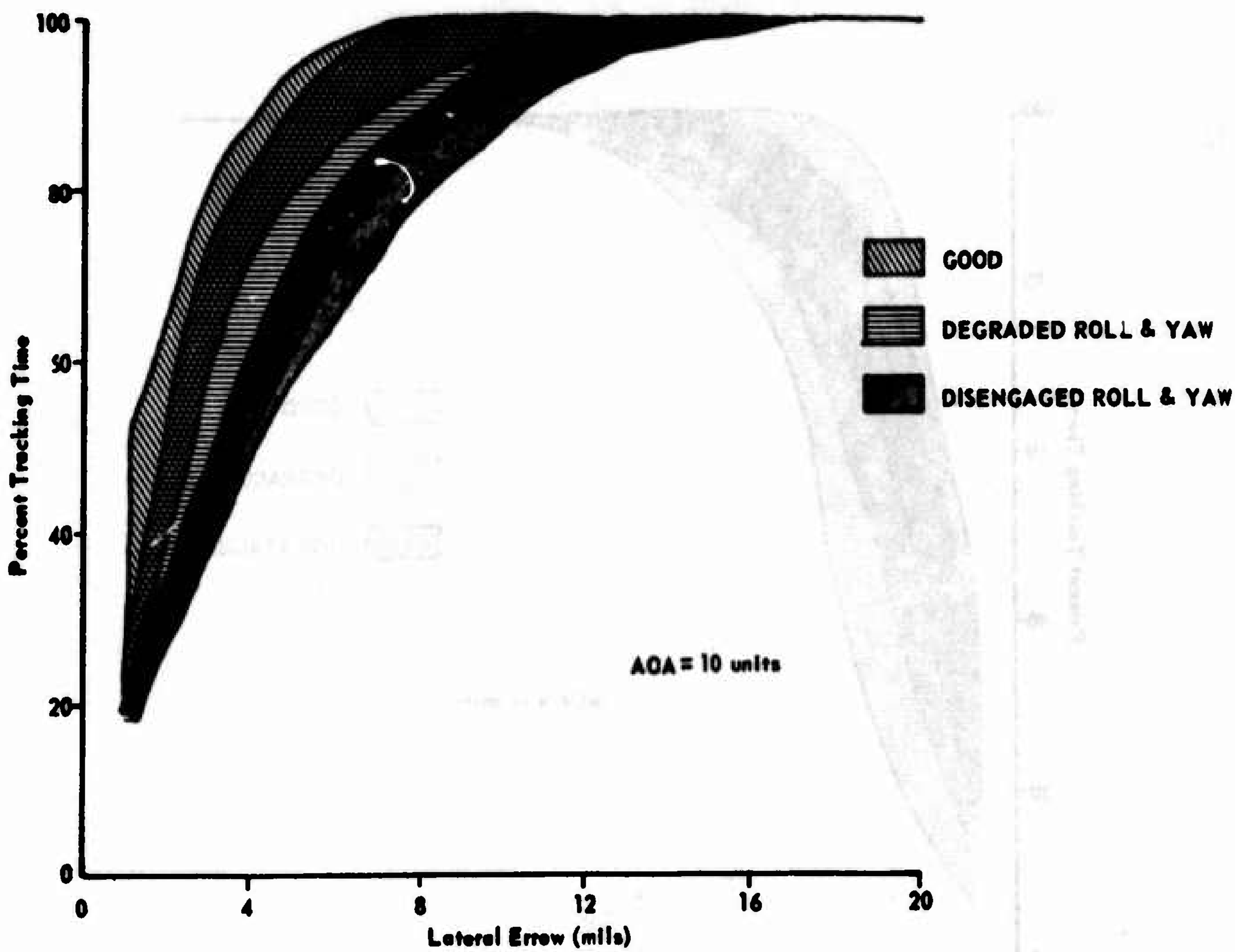


FIGURE 5 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

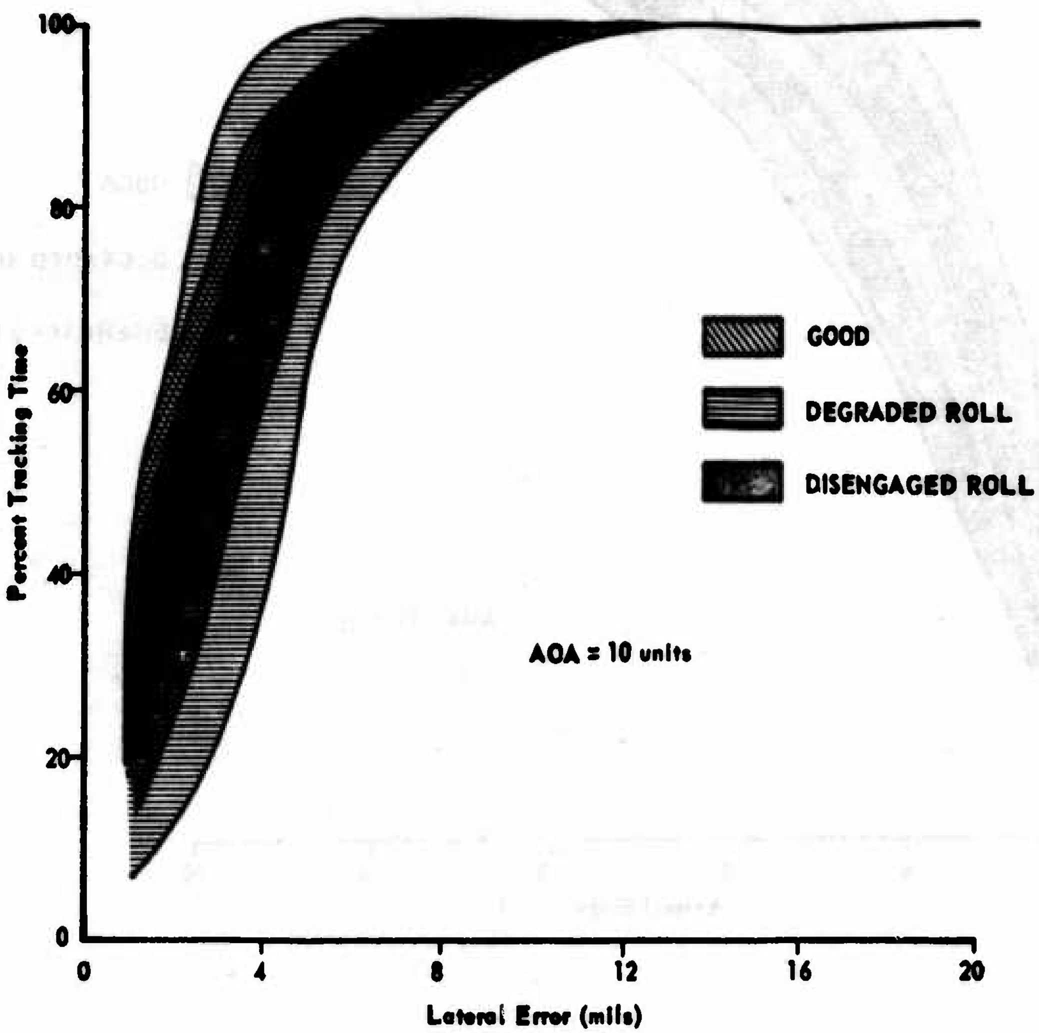


FIGURE 6 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

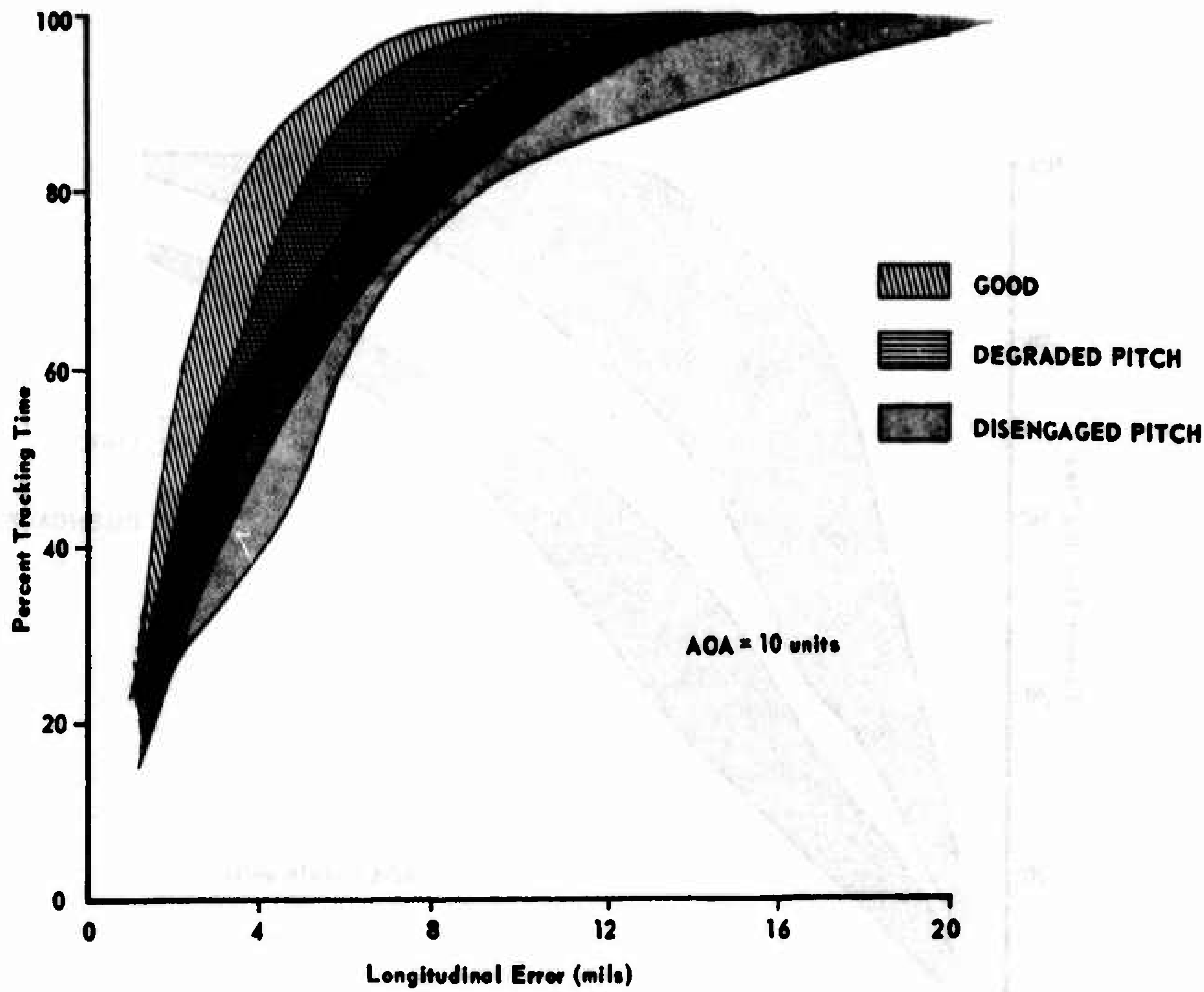


FIGURE 7 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

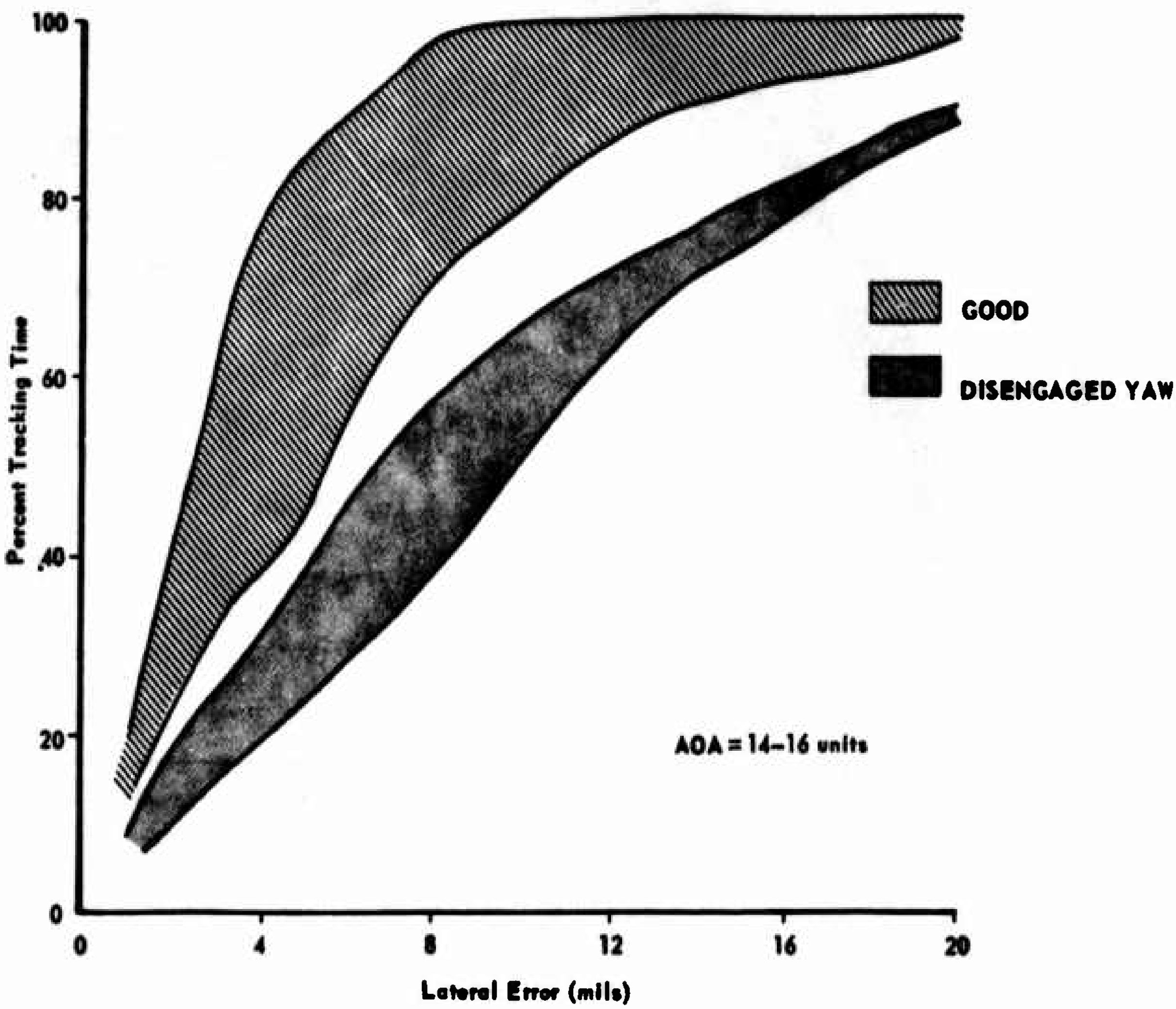


FIGURE 8 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

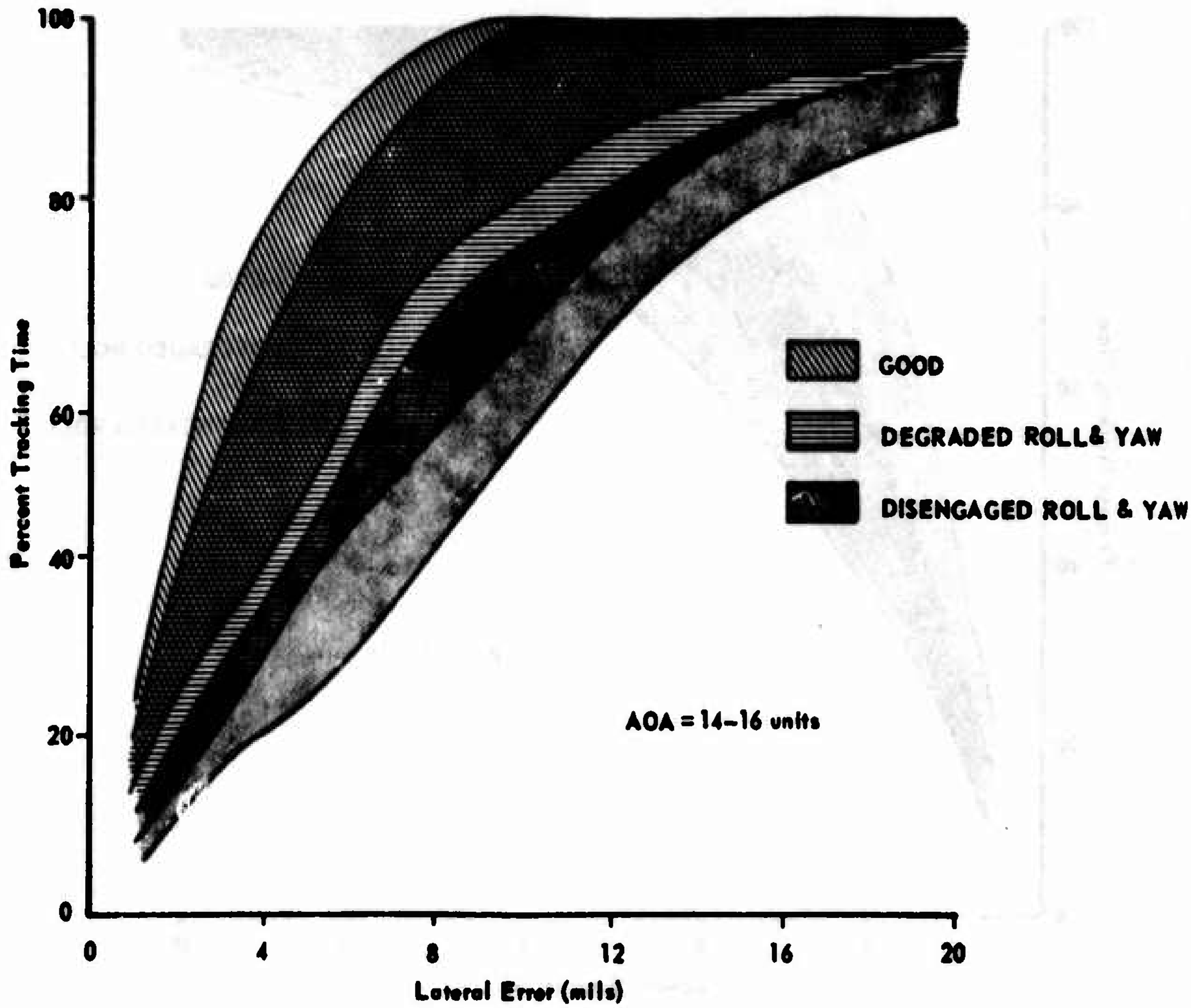


FIGURE 9 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

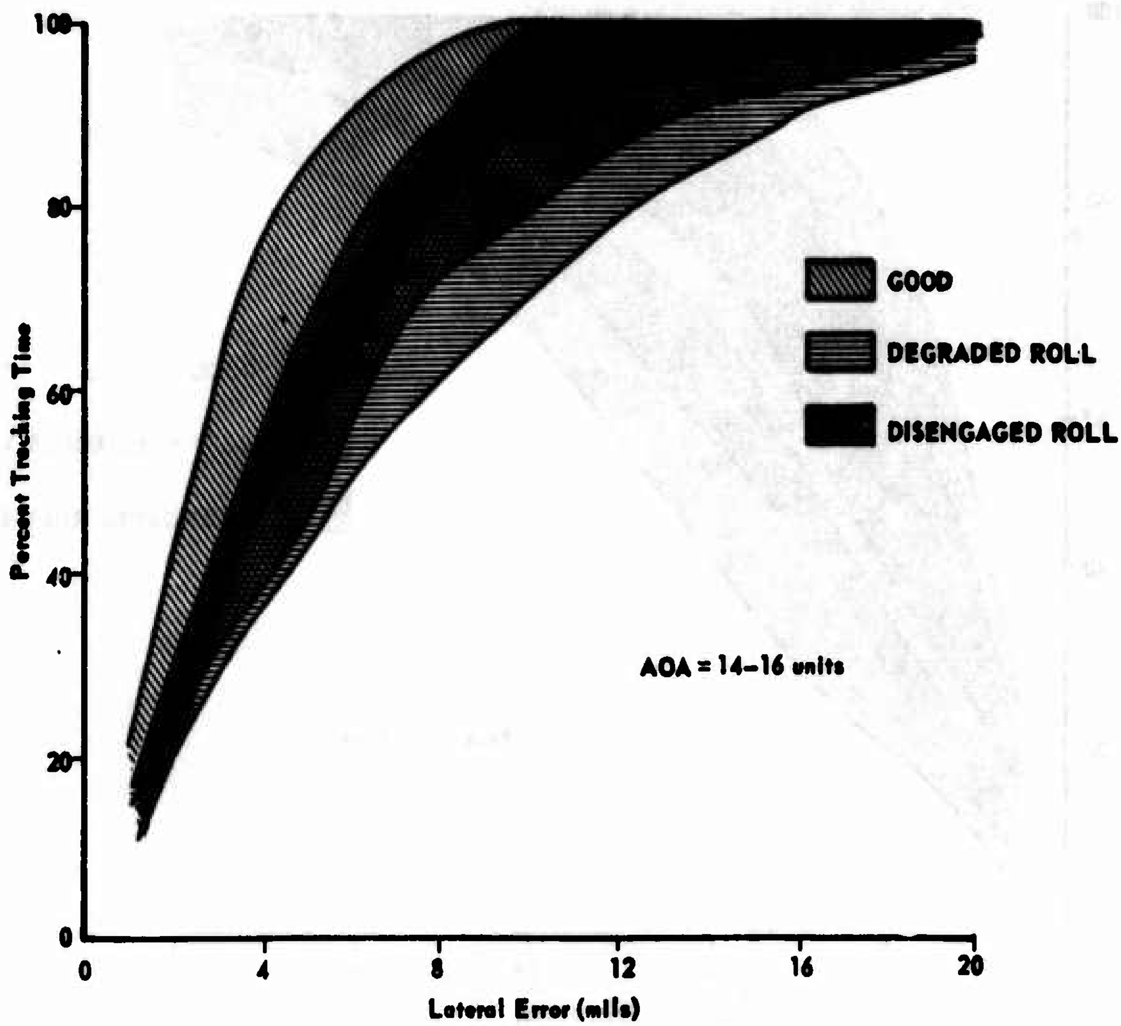


FIGURE 10 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE

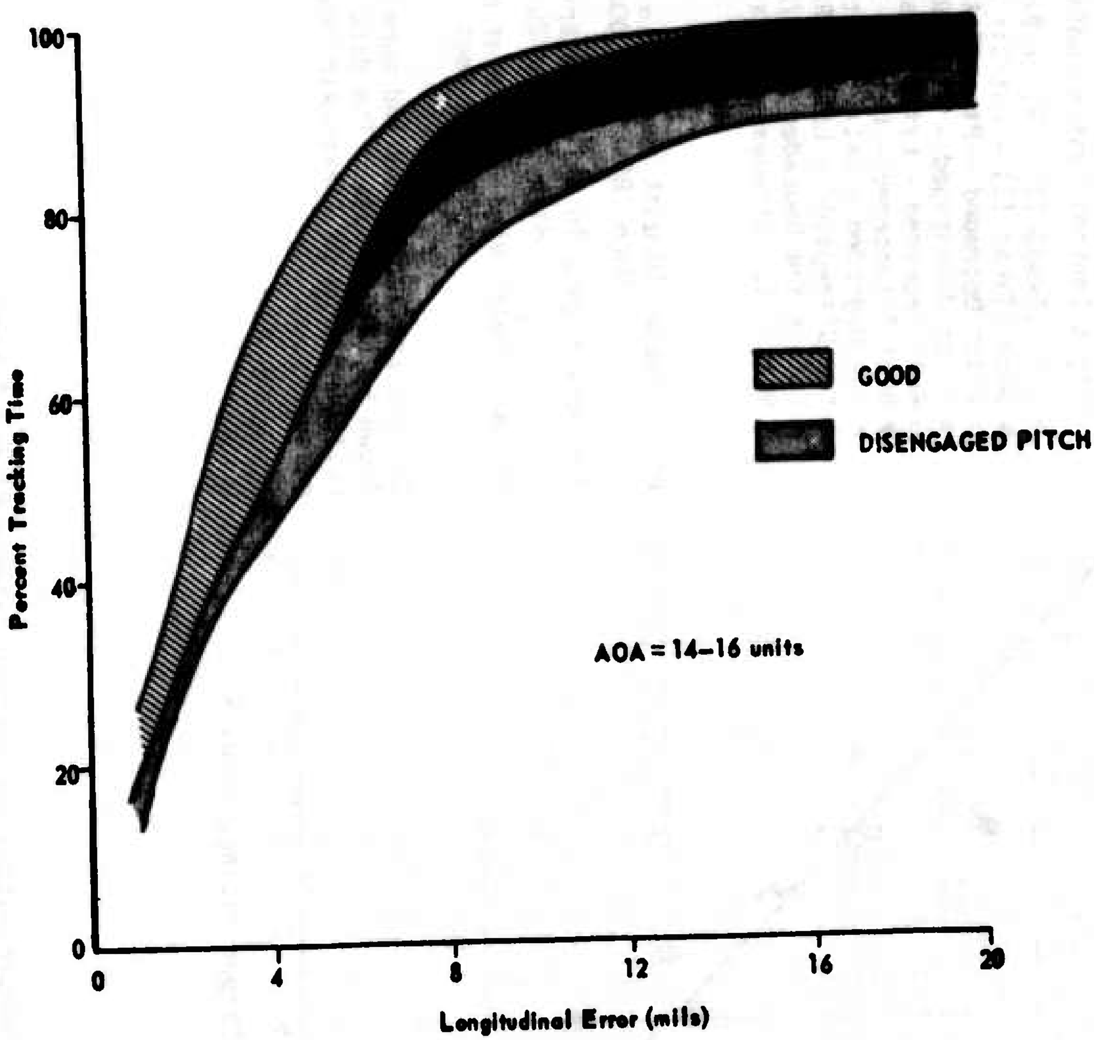
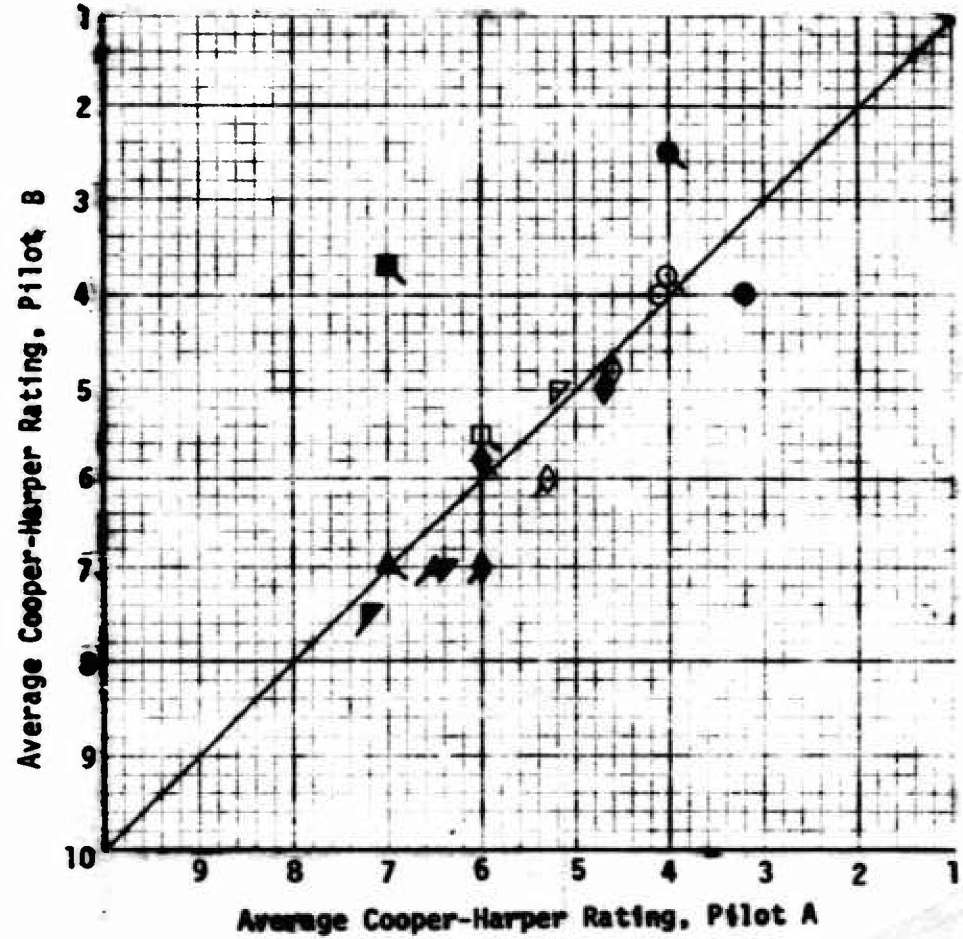


FIGURE 11 PERCENTAGE TRACKING TIME WITHIN GIVEN ERROR RANGE



Cooper-Harper Rating Correlation between Pilots A and B

Flight Control System Configuration

- ○ Good (TWeaD II) - Pitch Rating
- ● Good (TWead II) - Lat/Dir Rating
- □ Pitch Degraded - Pitch Rating
- ■ Pitch Disengaged - Pitch Rating
- ◇ Roll Degraded - Lat/Dir Rating
- ◆ Roll Disengaged - Lat/Dir Rating
- △ Yaw Degraded - Lat/Dir Rating
- ▲ Yaw Disengaged - Lat/Dir Rating
- ◸ Roll & Yaw Degraded - Lat/Dir Rating
- ◤ Roll & Yaw Disengaged - Lat/Dir Rating

No tic mark: 10 unit constant α turn at Mach .85 and 20,000 feet

Tic mark right: 15 unit constant α turn at Mach .85 and 20,000 feet

Tic mark left: Wind-Up turn at Mach .85 and 20,000 feet

Not all configurations and maneuvers were flown by both pilots. The data shown was collected from 62 Air-to-Air Tracking maneuvers.

Figure 12. Cooper-Harper Rating Correlation Between Pilots A and B

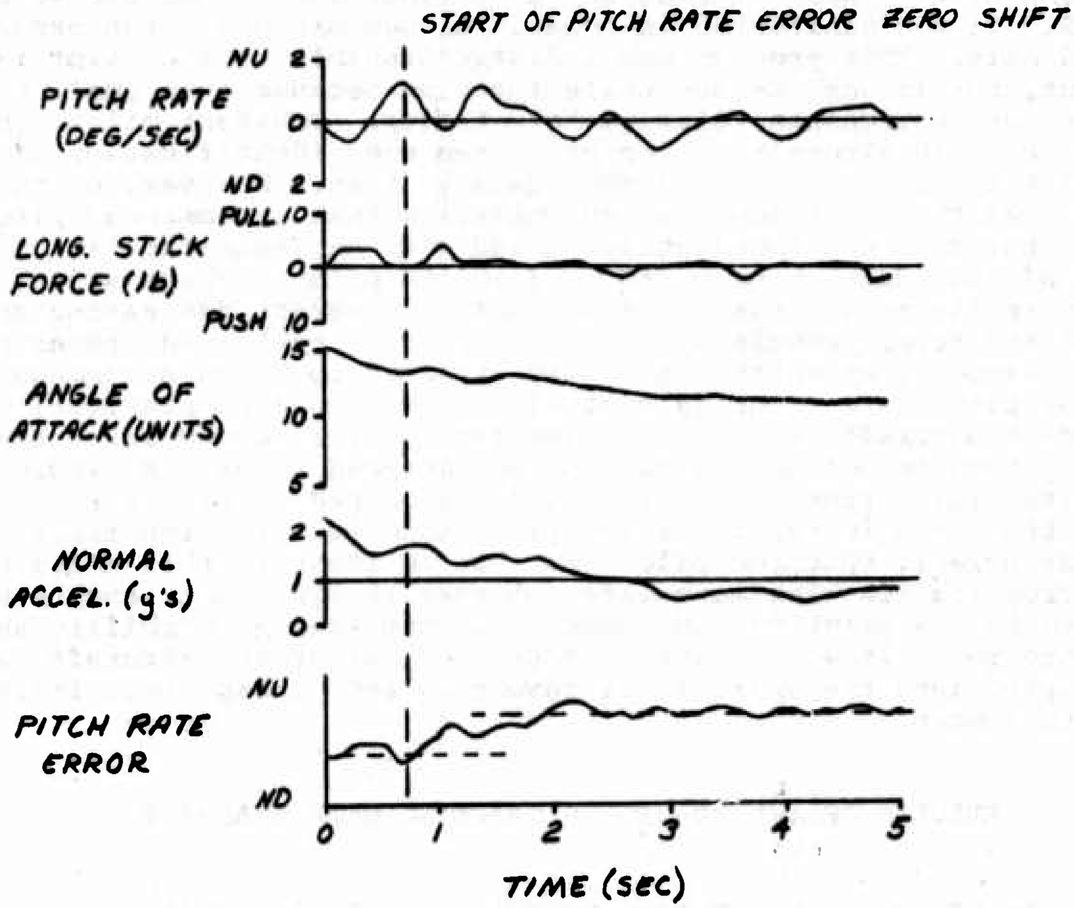


FIGURE 13 PITCH GLITCH TIME HISTORY

handling qualities, and aerodynamic phenomena such as pitch-up, wing rock, or buffet. How the aircraft felt to the pilot, and the gun camera film analysis were the two tools found most useful for analyzing handling qualities in a mission-oriented environment. Throughout the three stability levels and in both the longitudinal and lateral-directional axes, the ratings were very consistent between the two pilots (figure 12).

Pilot comments also pointed out problems which were not readily discernible in the pipper traces. For example, during the last one and a half months of the TWeaD II Program, a spurious anomaly developed in the pitch CAS. It was manifested in occasional uncommanded pitch excursions of 3 to 5 mils. This problem was indistinguishable to the pilot in normal flight, but it was obvious while tracking because even small pipper excursions are noticeable relative to a target. Constant pilot control inputs along with aircraft motion prevented easy identification of this "pitch glitch" using other available data sources. However, on one occasion when the pilot reported encountering this uncommanded pitch response, the data was immediately marked with an identification signal. A review of this data appeared to confirm the pilot's observation. At time zero in figure 13, the pilot attempted to arrest decreasing angle of attack and normal acceleration. The aircraft responded properly for about 0.7 seconds, at which time there appeared to be an uncommanded ramping of pitch rate error (a control system feedback parameter) with an attendant aircraft response. A few tenths of a second later the pilot responded to compensate for the uncommanded input. As indicated by the pitch rate error dashed line there appeared to be a zero shift, which is the probable source of the pitch anomaly. The important point to be made here is that the pilot was able to identify this small pitch anomaly from the tracking maneuvers, whereas it would not have been discovered by the pilot or engineers in a conventional stability and control program. It would have surfaced only after the aircraft had been accepted into the operational inventory and perhaps been introduced into combat.

RESULTS OF AIR-TO-GROUND TRACKING DATA ANALYSIS

Because of the very limited quantity of air-to-ground data acquired, neither of the air-to-ground tracking maneuvers investigated (dive-bombing and strafing) could be substantiated as valid techniques for evaluating closed-loop system performance in the air-to-ground mode. For this reason no air-to-ground data is presented in this report.

Further flight development of air-to-ground tracking test techniques and handling qualities should be pursued. (R 2)

FLIGHT CONTROL SYSTEM OPTIMIZATION USING TRACKING TEST TECHNIQUES

The technique for identifying handling qualities deficiences through air-to-air tracking also proved uniquely effective in optimizing the TWeaD II flight control system. This additional benefit was

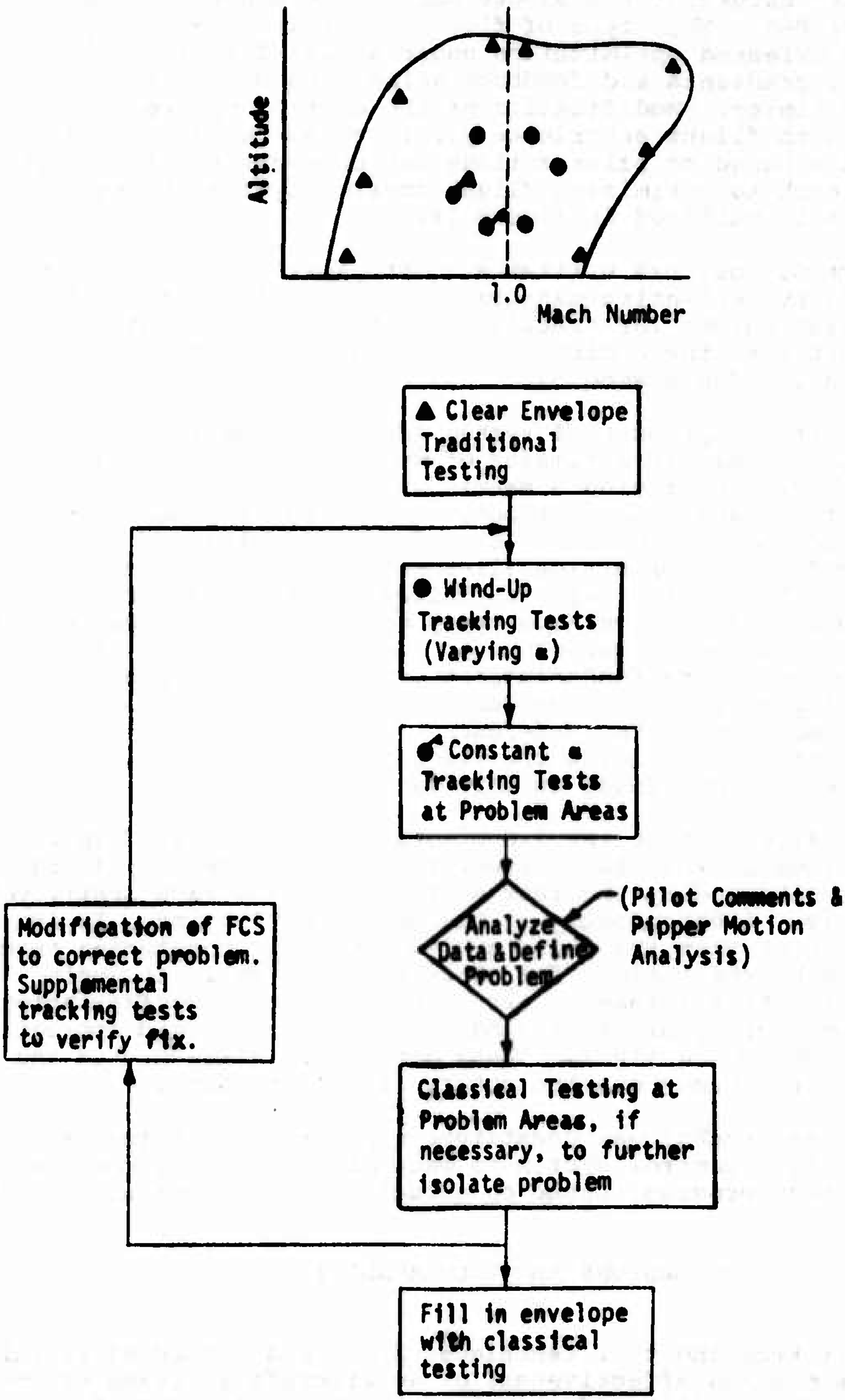


Figure 14. General Approach to Flight Control System Optimization

implicit in tracking test techniques, and was realizable because of the "adjustable" nature of the electrical flight control system used in the TWeaD II F-4. This type of flight control system was well suited to task oriented optimization under actual flight conditions since the model gradients and feedback gains were easily adjusted within certain limits. Modification of the control system parameters in accordance with flight experience permitted an optimum blend of flying qualities based on pilot ratings and comments and task performance. A general approach to optimizing flight control systems using tracking test techniques is outlined in figure 14.

Mr. Robert G. Hoey has written a short paper on test point selection for stability derivative maneuvers which is also pertinent to the selection of test points for tracking test techniques. This paper provides insight into the choice of test conditions for flight control system optimization (Reference 5).

The TWeaD II flight control system was optimized in three general steps. First, the initial estimates of model gradients and gains were checked and modified by flying a matrix of pitch pulses, wind-up turns, level accelerations and decelerations, various rolling maneuvers and roll pulses, and rudder doublets. Second, these gains and gradients were further refined by precision air-to-air tracking maneuvers (constant-α turns). Third, the gains optimized by precision tracking were verified by "gross" (or conversion type) maneuvering and then rechecked against precision tracking performance. In each step, the pilot's ratings and comments were fundamental to the optimizing process. The result was flying qualities which were optimally blended to best perform the designated mission tasks (Reference 6). Less than eleven flying hours were required to optimize the flight control system (pitch, roll, and yaw, including cross-feed) in this manner.

It is significant that the two pilots who participated in the optimization process exhibited characteristically diverse piloting techniques (as observed by the test engineers in the back seat), yet each pilot arrived independently at the same "best" gains. It is equally significant that the gains arrived at using constant-α tracking turns proved to be the optimum for other tasks as well, including air-to-ground tracking (clean to very high drag store configurations), close formation flying, air-refueling, ILS approaches, and approaches to accelerated and one g stall. These gains were also checked and found satisfactory throughout the entire flight envelope.

Tracking test techniques constitute a powerful tool for rapidly optimizing a flight control system to meet mission requirements early in the flight test program, based on actual flight experience. (R 3)

CONCLUSIONS AND RECOMMENDATIONS

Air-to-air tracking test techniques provide a method of rapidly evaluating the mission effectiveness of an aircraft in terms of its handling qualities (ability of the pilot to precisely control the aircraft attitude) early in the flight test program. This technique uses air-to-air wind-up tracking turns and constant angle of attack

tracking turns to examine the aircraft throughout the maneuver environment for which it was designed by analyzing pilot rating and comments, and gunsight pipper motion relative to the target. Time histories of this motion in the longitudinal and lateral-directional axes combined with a pipper error analysis and pilot comments rapidly isolate stability and handling qualities problems so that if necessary they may be more closely investigated by conventional stability and control testing. This technique proved to be a powerful tool in developing the TWeaD II flight control system and in uncovering handling qualities problems which would not have been discovered conventionally.

1. Tracking test techniques should be used early in flight test programs to determine areas of stability and handling qualities deficiencies (page 13).

While the development of air-to-air tracking test techniques was successful, the development of air-to-ground tracking test techniques was restricted by the limited data acquired. Additional development testing should be pursued to determine what air-to-ground tracking test techniques would be useful in rapidly evaluating ground attack effectiveness in terms of stability and handling qualities.

2. Further flight development of air-to-ground tracking test techniques and handling qualities evaluation should be pursued (page 32).

Tracking test techniques were a powerful tool for rapidly optimizing the TWeaD II flight control system to provide the best practical blend of flying qualities for the aircraft's mission requirements. By performing task oriented tracking maneuvers the pilot received a very clear impression of the effectiveness of the airplane's flying qualities and how they could be improved. The control system model gradients and gains were then modified to more nearly provide the desired flying qualities. In the case of the TWeaD II F-4, the control system gains arrived at using air-to-air tracking test techniques proved to be effective throughout the flight envelope, and for all other mission tasks, including close formation flying, air-to-ground tracking, air-refueling, and ILS approaches.

3. Tracking test techniques should be used early in flight test programs to assist in optimizing flight control systems (page 34).

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9. Rickard, Richard R., Major, USAF, et al., Stability and Control Evaluation of an F-4C Aircraft with a High Gain Adaptive Control Augmentation System, FTC-SD-71-17, Air Force Flight Test Center, Edwards AFB, California, June 1971.

Appendix A

DESCRIPTION OF THE AIRCRAFT'S THREE DIFFERENT STABILITY LEVELS

The F-4C aircraft used to conduct the tracking test techniques studies incorporated a high gain CAS. As previously mentioned, this system was designated the TWeaD II CAS and was developed under the auspices of the Air Force Flight Dynamics Laboratory. A detailed description of the augmentation system and its development are contained in references 6, 7, 8, and 9.

The capability to vary system gains during flight, together with the broad selectivity of feedback functions which could be varied, provided the capability of altering the apparent stability over a wide range. Program time constraints and associated costs limited the stability level variations for this program to three; i.e., good, degraded, and unaugmented (CAS disengaged) aircraft. The good aircraft corresponded to one with the final, developed TWeaD II CAS. The unaugmented aircraft corresponded to an unaugmented F-4C airframe and its associated hydraulic control system. The degraded aircraft fell somewhere in between. Figures 15 and 16 are block diagrams of the longitudinal and lateral-directional control systems with selected good (indicated by boxes) and degraded (D) augmentation settings. Where degraded settings for the particular axes pitch (P), roll (R), and yaw (Y) are indicated, all other gain settings are for the good aircraft.

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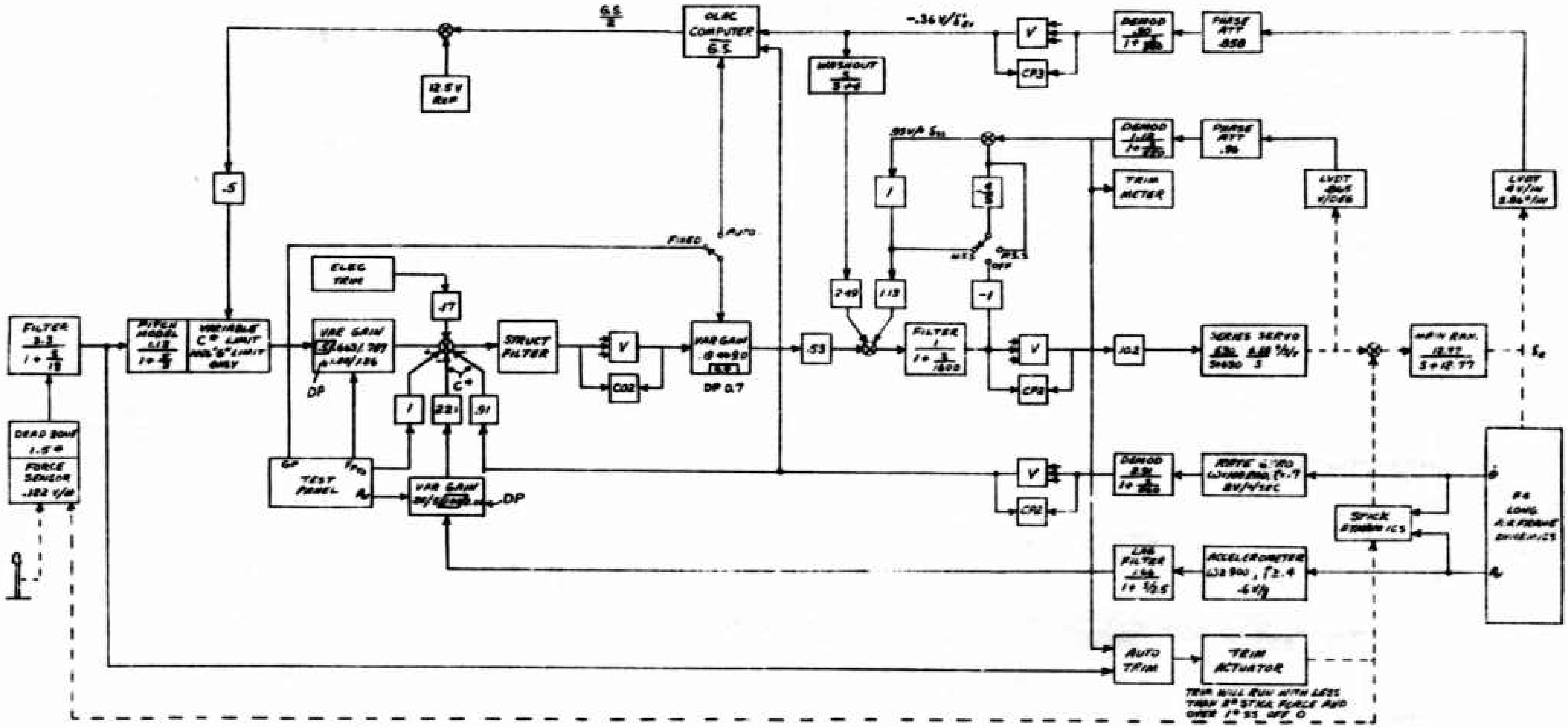

☐ - GAINS APPEARING IN BOX ARE FINAL SYSTEM GAINS (GOOD A/C)

DP - DEGRADED PITCH

FIGURE 15 LONGITUDINAL BLOCK DIAGRAM, F-4C TWEAD II CAS

STRUCTURAL FILTER (WITH DOUBLE NOTCH) TRANSFER FUNCTION

$$XFR\ FCN = (1.68)\left[\frac{s^2 + .12(121)s + 121^2}{s^2 + 1.02s + 85^2}\right]\left[\frac{.25(s+4)}{s+1}\right]\left[\frac{.403(s^2+.6(66)s+66^2)}{s^2+1.02s+85^2}\right]\left[\frac{.87(s+10)200}{(s+8.7)(s+200)}\right]$$

$$= (36.5)^2\left[\frac{s^2 + .12(121)s + 121^2}{s^2 + 1.02s + 85^2}\right]\left[\frac{s^2+.6(66)s+66^2}{s^2+1.02s+85^2}\right]\left[\frac{(s+4)(s+10)}{(s+1)(s+8.7)(s+200)}\right]$$

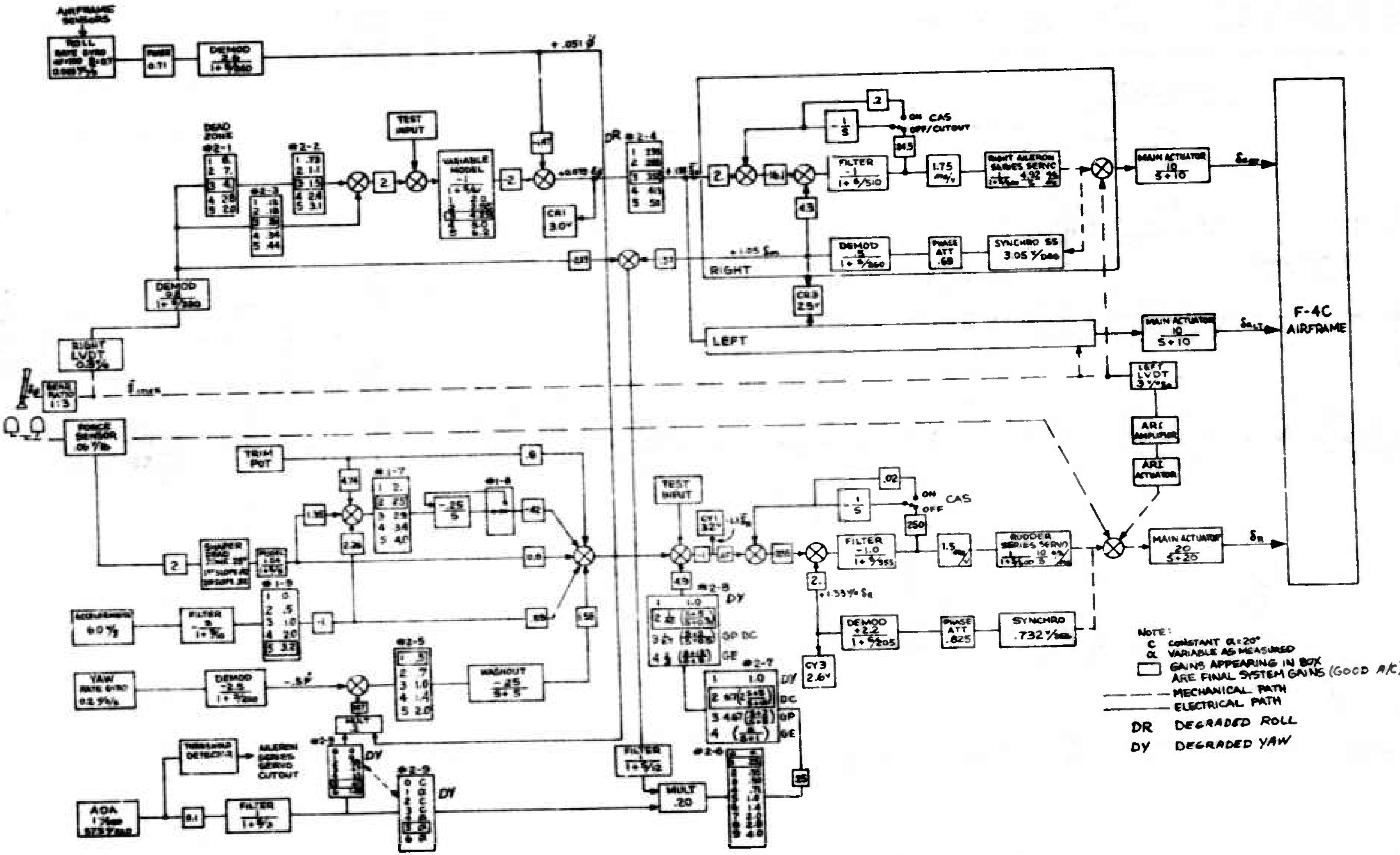

Figure 16 Lateral-Directional Block Diagram, F-4C TWeaD II CAS

TRACKING TEST TECHNIQUES (PROCEDURAL INFORMATION)

This appendix is presented in the form of a User's Guide, in essentially the same format as Tracking Test Techniques will be presented in a future edition of the AFFTC Stability and Control Manual.

INTRODUCTION

The importance of mission-oriented pilot-in-the-loop handling qualities has long been recognized by the flight test community. Traditionally the only tool available for evaluating closed-loop system performance has been subjective pilot opinion, in the form of the Cooper-Harper rating scale. Air-to-air tracking test techniques offer the pilot and engineer a means of systematically examining and evaluating the closed-loop system performance of fighter type aircraft.

The use of tracking test techniques to evaluate flying qualities is based on an analysis of pilot observation (Cooper-Harper rating and additional comments) and pipper motion relative to a target during tracking maneuvers. The philosophy of tracking test techniques is that a pilot attempting to perform a precision tracking task will be able to easily identify flying qualities deficiencies which make it difficult for him to perform the task well. If the maneuver and test condition at which the task is performed are carefully selected and controlled, data can be obtained which will permit the deficiency to be isolated. Modifications to the flight control system can then be designed to correct the deficiencies.

The maneuvers and techniques which will permit the engineer to exercise the control required to obtain good data are outlined and explained in this write-up, including maneuver techniques, perturbation and precision tracking techniques, test point selection, target pilot responsibilities, and data considerations.

Properly used, tracking test techniques constitute a powerful flight test tool for evaluating flying qualities, identifying deficiencies, and optimizing the flight control system. Several important advantages are offered over traditional methods. These are:

1. The pilot and engineer can examine flying qualities during mission-oriented maneuvers and tasks, thus providing insight into potential mission oriented flying qualities deficiencies early in the test program.

2. The pilot is in the control loop throughout the test providing closed-loop flying qualities information, rather than simply performing an initial test input to obtain open-loop data.

3. The engineer can select and rapidly scan areas of the flight envelope for potential flying qualities deficiencies, and then zero in on those deficiencies for a closer look.

4. The only test instrumentation required for gathering basic handling qualities information is a gun camera that will photograph through the gunsight combining glass. Gun cameras are often standard equipment on fighter type aircraft.

It is important not to confuse tracking test techniques with the operational tracking and gun firing techniques associated with an actual combat encounter. The maneuvers and techniques implemented in tracking test techniques are not intended to be real-world operational or combat maneuvers and techniques. They are closely controlled flight test maneuvers and techniques carefully designed and developed to elicit flying qualities information which will be useful and instructive in a mission oriented context, i.e. in developing the aircraft to be as closely suited as possible to its design mission, in terms of the pilot's ability to precisely control aircraft attitude. In this respect it is certainly expected that the results of tracking test techniques (a better handling airplane) will favorably impact the operational pilot's ability to control his aircraft during combat encounters. But it would be a mistake to assume that the data gathered using these techniques directly reflect such overall mission effectiveness parameters as the likelihood of a kill. The overall combat effectiveness of the airplane is a function of many considerations. Tracking test techniques provide a measure of that portion of mission effectiveness which is related to the pilot's ability to precisely control the aircraft attitude.

Scrupulous observance of the techniques herein outlined and careful attention to procedure are very important if useful data is to be realized.

OVERVIEW

Figure 14 (page) offers a schematic view of the role played by tracking test techniques in the overall test evaluation of flying qualities, identification of deficiencies, and flight control optimization. After the flight envelope has been cleared by traditional test methods, test points are selected at which tracking test techniques will be performed to evaluate flying qualities. The selection of test points is based on wind tunnel results, early flight data, and the area of the envelope where the design mission will most likely be performed, At each selected test point wind-up tracking tests are used to examine the useable angle of attack range of the airplane. Any deficiencies uncovered by the wind-up tracking tests are more closely investigated by constant angle of attack tracking tests conducted at the angle of attack/Mach number problem area. Pilot ratings and comments and a pipper motion analysis of the tracking test data are used to define any flying qualities deficiencies so that if necessary additional classical testing can be conducted at the problem areas. However, tracking testing is a fine resolution technique and may not always require classical exploration or verification. The data from the classical tests and the tracking tests are used to modify the flight control system and correct the deficiencies. Tracking tests are then used to verify those corrections. If no flying qualities deficiencies are uncovered by the tracking tests, the data are used to document that fact and to illuminate the flying qualities characteristics of the airplane.

This approach to flying qualities evaluation provides an early look at mission oriented pilot-in-the-loop handling characteristics and potential deficiencies, and provides a valuable opportunity to make corrections early in the test program with the minimum adverse effect on program schedules and a minimum of duplicated test effort.

PRELIMINARY PLANNING

Preliminary planning for performing tracking testing should include an assessment of instrumentation and analysis requirements (see sections entitled "Instrumentation Requirements" and "Data and Related Considerations"), and test point selection requirements (see section entitled "Test Point Selection"). These requirements will depend on the type and extent of handling qualities and flight control system information being sought: whether basic handling qualities information, or a more extensive evaluation and definition of handling qualities and related deficiencies, or flight control system optimization. The selection of test points will depend on the aircraft and configuration, how much flight data is available, whether handling qualities problems are anticipated in certain areas, etc.

INSTRUMENTATION REQUIREMENTS

Instrumentation requirements are dependent on the type of information desired.

It is one of the advantages of tracking test techniques that basic mission-oriented, pilot-in-the-loop handling qualities information can be acquired with a bare minimum of instrumentation, i.e. a gun camera which will photograph through the gunsight reticle. In some cases a gun camera will already be present on the test aircraft. This requirement for minimum instrumentation is particularly advantageous in certain cases.

If, in addition to a basic evaluation of handling qualities, it is desired to isolate and define deficiencies or optimize the flight control system, it will be necessary to gather additional data, including flight path and control system information. This will require more extensive test instrumentation, i.e. a gun camera as well as normal stability and control and flight control system information.

PILOT PROFICIENCY

Tracking test techniques implement maneuvers and piloting techniques which differ considerably from those learned by the pilot during normal operational training and used in combat. Because of these differences, and because the opertional techniques are second nature to the pilot, emphasis must be placed on acquiring and maintaining pilot proficiency in tracking test techniques.

The maneuvers and piloting techniques developed for tracking testing are critical to the acquisition of useful data, and must therefore be carefully and accurately implemented. Experience indicates that there is a definite learning curve associated with mastering these techniques. A pilot who is umfamiliar with tracking test techniques, or with the test aircraft and its handling qualities

characteristics, will require several familiarization maneuvers, or one or two familiarization flights before good data and pilot comments can be obtained.

It is just as important to stress the proficiency of the target pilot in performing the test maneuvers. These maneuvers are important in terms of both test conditions and flight path, and it is the target pilot who establishes and maintains these test parameters (see section on "Target Pilot Responsibilities").

TEST POINT SELECTION

Three selectable test parameters exercise the dominant influence on airplane flying qualities: Mach number, angle of attack (α), and dynamic pressure ($\bar{q}$). Rigid airplane flying qualities are affected only by Mach number and angle of attack, while the flying qualities of a flexible airplane are affected by dynamic pressure as well. Tracking test techniques permit the engineer to rapidly survey the interesting range of these three parameters with a relatively few maneuvers, and to scrutinize their effect on flying qualities.

In selecting the initial test conditions at which tracking test techniques will be performed, it may be helpful to examine the flight envelope in terms of dynamic pressure versus angle of attack plots and Mach number versus angle of attack plots (figure 17). During the early stages of optimizing a flight control system or evaluating the handling characteristics of a new or untried design, the engineer will probably wish to begin tracking testing in the middle of the flight envelope. As experience with the airplane and control system accumulates, tracking test points may be directed towards the boundaries of the envelope with commensurately added confidence. Wind tunnel test results and early flight test data will provide the engineer with an initial idea of where on these flight envelope plots potential problems may exist. For example, wind tunnel data may show that for a particular aircraft configuration C_{N_β} is lowest at high angles of attack around Mach .95. Certainly the engineer will want to investigate this region thoroughly in order to analyze the potential effect on mission-oriented flying qualities and, if warranted, to investigate possible control system changes to correct any deficiencies. Wind-up tracking tests in the vicinity of Mach .95 are a good way to initially assess the situation.

Knowledge of the airplane's design mission role and the area of the flight envelope where that role will likely be performed will also aid in initial test point selection. For example, the air superiority mission will most likely be performed at Mach numbers of .3 to 1.2 and throughout the range of angle of attack available to the pilot. Initial exploratory coverage of this portion of the envelope might be obtained with wind-up tracking tests performed from Mach .3 to Mach 1.2, or with constant angle of attack slowdown turns performed over the useable angle of attack range.

It is apparent that this technique permits large areas of the flight envelope to be surveyed for potential flying qualities deficiencies with a minimum of test maneuvers and flight hours.

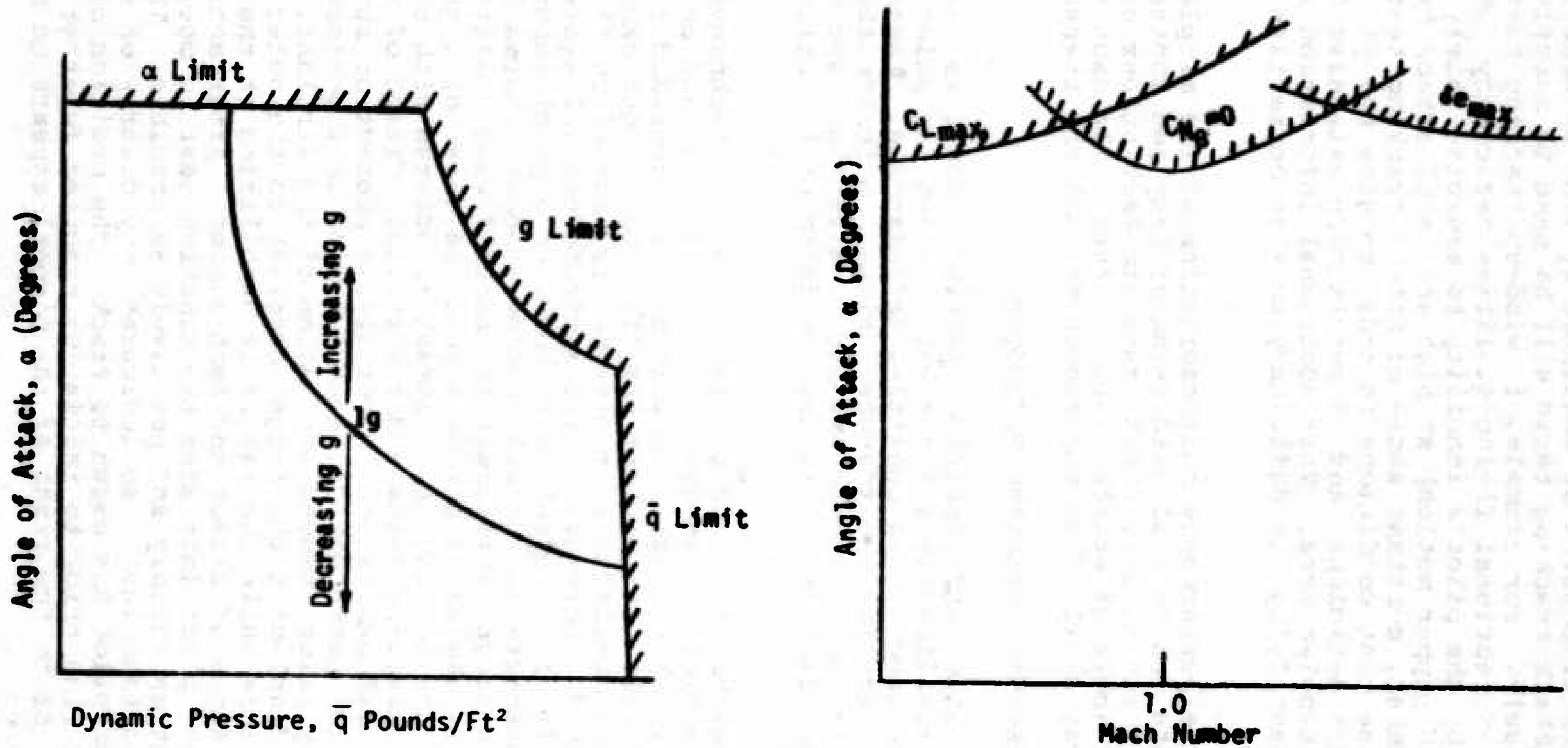

Figure 17. Flight Envelope in Terms of Dynamic Pressure and Mach Number versus Angle of Attack

Based on the data obtained during the initial tracking tests survey, the engineer may want to look at other test conditions. After a problem area has been discovered or confirmed by wind-up tracking tests, constant angle of attack tracking tests will be used to scrutinize the deficiency more closely. For example, if wind-up tracking tests reveal a potential lateral-directional flying qualities deficiency (characterized, for example, by the pilot's inability to exercise fairly close control over azimuth pipper motion) at high angles of attack between .85 and 1.0 Mach number, constant angle of attack tracking tests should be performed at those test conditions in order to give the pilot a more extensive look at the deficiency and to permit more extensive data acquisition in the problem area. This additional information will aid in isolating and identifying the deficiency so that corrective measures can be instituted.

Depending on the performance characteristics of the airplane, transonic test points can be evaluated using wind-up and constant angle of attack tracking tests at a constant transonic Mach number or by performing constant angle of attack tracking tests while Mach number is permitted to decay slowly from supersonic through the transonic region.

PERTURBATION AND PRECISION TRACKING TECHNIQUES

Special perturbation and precision tracking techniques are used in tracking tests to significantly aid the engineer and the pilot in uncovering and describing flying qualities deficiencies. These special techniques are necessary for two reasons. First, to insure that potential deficiencies are unmasked and made manifest and second, to aid the engineer and the pilot in describing and defining the deficiencies that are discovered.

Together the perturbation and precision tracking techniques insure that the airframe/control system dynamics are initially and continually excited during the tracking test. An aircraft with degraded flying qualities characteristics can present the illusion (on gun camera film) of having good flying qualities if the pipper is allowed to float near the target undisturbed. However, if the airframe/control system dynamics are excited - either by buffet, wing rock, or a pilot input - then the poor handling characteristics will become evident. Normally this "natural" excitation proves sufficient to unmask flying qualities problems, particularly at angles of attack beyond the onset of light buffet. However at the low angles of attack associated with constant low angle of attack tracking tests and the initial portion of wind-up tracking tests, natural excitation is not always present or sufficient. To insure good initial perturbation, each tracking test performed must be initiated by pilot induced excitation of the airplane. This is accomplished by displacing the target aircraft to the outer ring of the gunsight reticle while the target is stabilizing at the turn test conditions of angle of attack and Mach number. After achieving these conditions, the pilot initiates the tracking test by moving the pipper to the target as rapidly and positively as possible. This initial perturbation technique also indicates very clearly on the gun camera film that the pilot has begun to track. The position of the target on the outer ring prior to initiating tracking (whether above, below, to the left, or to the right of the pipper) appears to make little if any difference.

Once the airframe/control system dynamics have been initially excited in the manner just described, the precision tracking technique will serve to perpetuate the dynamics excitation throughout the tracking test. This technique differs considerably from tracking techniques used in a combat situation. In combat, using a lead computing gunsight, a specified period of time (usually one second) is required to compute a tracking solution prior to firing, during which time the pipper must be stabilized relative to the target (the pipper need not be on the target during this time so long as it is stabilized near it). Once a solution has been computed the pilot can then effectively "walk" his bullet stream from that position across his target.

The precision tracking technique used in flying qualities evaluation makes use of a fixed (i.e. non-computing) gunsight, so that no extraneous pipper motion is introduced by the coupling of gunsight and aircraft dynamics. The engineer and the pilot select a prominent feature on the target aircraft to be used as the precision aim point (e.g. a tail pipe). During the tracking test the tracking pilot will use the precision aim point on the target aircraft as his target. His entire mental concentration and physical effort must be devoted to keeping (or attempting to keep) the pipper on the precision aim point. Even the smallest pipper excursion from the precision aim point (even a one mil excursion) must be the object of immediate and positive corrective action. The result of this technique is to make the tracking errors worse than if the pipper were allowed to float near the target undisturbed (especially if the aircraft exhibits poor flying qualities and the pilot is not permitted to use the rudder pedals). Despite the reduced tracking accuracy, the precision tracking technique serves the very important function of perpetuating the initial perturbation of airframe/control system dynamics, and has consequently proved to be the most effective technique for manifesting and magnifying flying qualities deficiencies.

Reiterating, the primary task performed by the tracking pilot is to keep the gunsight pipper on the precision aim point on the target aircraft. It is imperative that the tracking pilot make a continuous and concerted positive effort to immediately return the pipper to this point on the target on every occasion that it wanders away. The pipper must not be permitted to float near the target, nor to float into the target, nor to stabilize in order to facilitate returning it to the target. As a tracking test technique, floating the pipper masks any tendency for the airplane dynamics to be excited by the pilot's efforts to precisely control the aircraft (pipper) motion.

The tailpipe, or one of the tailpipes, of the target aircraft is a convenient precision aim point for the tracking pilot. If this isn't possible, the tracking pilot should be reminded as often as required (at least prior to each mission) that he must constantly and consistently use the precision aim point (whether tailpipe or other feature) on the target aircraft as his target. This is important because experience indicates that during the mental and physical concentration of tracking the pilot often lapses unintentionally into the more natural technique of aiming at the "center" of the target.

If the tracking pilot fails to consistently track a selected aim point, i.e. if he changes his aim point during a tracking run, or from one tracking run to another, the data acquired becomes less meaningful. If the pilot arbitrarily changes his aim point, or only aims at the aircraft in general the gun camera film cannot be properly scored because the scorer will then be using an indeterminate aim point. Consequently the pipper error data will be erroneous and misleading.

With certain exceptions, the tracking pilot is not permitted to use the rudder pedals during tracking testing, i.e. his feet must be flat on the floor. This requirement arose because it was observed that some pilots are capable of completely masking flying qualities deficiencies through judicious rudder coordination. By not permitting the pilot to use the rudder pedals, deficiencies can be observed which might otherwise be inobvious. Those deficiencies will be more obvious to the pilot and will also be more apparent in the pipper motion analysis.

There are two exceptions to the proscription against using the rudder pedals. The first exception is during the early stages of tracking testing, when the pilot may be relatively unfamiliar with the airplane. Use of the rudder pedals at that time will serve to increase the pilot's competence and familiarity with a new airplane or configuration while still pointing out serious flying qualities deficiencies which cannot be attenuated even with a good roll and yaw interconnect.

The second exception occurs later on during tracking testing, after flying qualities deficiencies have been discovered using the "feet off" technique. At that point it will prove instructive to accomplish some additional tracking with the pilot permitted to use the rudder pedals. This will be helpful in assessing the usefulness of the rudder in tracking and in establishing the basis for proposing corrections for the deficiencies.

TARGET PILOT RESPONSIBILITIES

The pilot of the target aircraft performs an extremely important function in tracking test techniques, and he must perform that function well if good data is to be obtained. It is the target pilot's responsibility to establish and maintain the desired test conditions of Mach number and angle of attack throughout the tracking maneuver. Since the test aircraft will be tracking the target aircraft, it is apparent that any error or variation in the test conditions will be reflected in the data acquired by the tracking aircraft. The tracking pilot will have his head "out of the cockpit" and his eyes and attention focused on the target aircraft, so it is the target pilot who must be alert to changing test parameters and take corrective action.

It is also the target pilot's responsibility to initiate the tracking maneuver smoothly, gradually, and in cooperation with the tracking pilot, so that the tracker is not thrown off early in the maneuver or forced into a "square corner". Particular care must be exercised during wind-up tracking maneuvers, where angle of attack is constantly changing and the rate of increase of angle of attack must be closely controlled.

One of the fundamental assumptions of the pipper motion analysis performed on the gun camera film data is that none of the apparent pipper motion visible in the film is attributable to motion of the target aircraft. That is, it is assumed that the target aircraft is motionless relative to the tracking aircraft, so that all of the observed pipper motion is in response to the tracking pilot's control inputs. That is why it is so important that the target pilot be smooth and accurate in leading the tracking aircraft through the tracking maneuver.

The importance of the target pilot is central to the successful acquisition of useful, constructive data. He should be carefully briefed and debriefed respecting his role in the test mission.

TRACKING TEST MANEUVERS

Unless a specific problem is to be investigated, windup tracking turns will be the first tracking maneuvers performed. These maneuvers will enable the pilot and the engineer to rapidly examine the aircraft's handling qualities throughout the operational range of angle of attack at various Mach number and dynamic pressure test conditions.

Subsonic Wind-up Tracking Turns:

Either of two techniques may be used to initiate this maneuver. In one, the target aircraft establishes a 30 degree banked turn on the tracker's command, with the tracker in trail. When this condition is established at the desired Mach number and altitude, the tracker's gun camera and data system are turned on and the tracker clears the target pilot to initiate the wind-up turn. The other technique is to align the tracker aircraft slightly below and inside the target in 1 g level flight. After activating his gun camera and data system the tracker clears the target, and the target proceeds to roll into the wind-up turn. In either case, after he is cleared to initiate the maneuver the target pilot establishes an angle of attack buildup of approximately one degree every two seconds while the tracking pilot attempts to track the precision aim point as closely as possible throughout the maneuver. The first technique for initiating the wind-up tracking turn is normally preferred because it is easier to avoid the target's jetwash.

The tracking pilot must activate his data correlation switch, if available, immediately upon initiating tracking and release it as soon as he terminates the tracking effort. If a data correlation switch is not available, another means of correlating the data will be necessary (see section entitled "Data and Related Considerations").

The distance between the target and the tracking aircraft is somewhat critical and should be maintained within certain limits. The tracking pilot must be able to clearly see the precision aim point on the target and it must be clearly visible on the gun camera film as well. An optimum range is 1500 ±500 feet. If the tracker is too close to the target, avoiding the jetwash tends to become a problem and detracts from the pilot's attention to tracking. If available, a ranging radar is a convenient way to maintain the desired separation distance. Otherwise the target wingspan may be used to estimate and control range.

The tracker pilot must not use the rudder pedals at any time while tracking (with the exceptions noted in the section entitled "Perturbation and Precision Tracking Techniques") and must concentrate on moving the pipper back to the precision aim point at all times, even if that distance is only one mil. The tracker must not allow the pipper to float near the target or to float into the target. A positive tracking effort is essential.

The maneuver is terminated on command of the tracker pilot after the target calls achievement of maximum angle of attack, when the target or tracker aircraft becomes uncontrollable to the point that tracking becomes unreasonable, or when the desired test conditions have deteriorated excessively. For data correlation purposes, the pilot should briskly move the gunsight reticle away from the target immediately after he terminates tracking.

Supersonic Wind-up Tracking Turns:

The technique for performing supersonic wind-up tracking turns is the same as that discussed for subsonic wind-up turns. However there are some additional performance-related considerations appropriate to high angle of attack supersonic flight. For example, to maintain 1.2 Mach number up to 19 units angle of attack with an F-4 tracking an F-4 requires careful attention to Mach number and a very nose low (nose down) attitude with attendant loss of altitude (6,000 to 8,000 feet). The high drag attendant on supersonic high angle of attack maneuvering means that Mach number can decay very rapidly. Further, because of the higher speed, it becomes more critical to correctly judge when to start turning after the target aircraft. If the tracker follows too soon, he may end up in jetwash and if he delays too long, he may have to negotiate a "square corner" in order to keep the pipper on the target. This would not normally create a problem except that the rapid angle of attack onset required by a "square corner" disrupts the smooth progression of angle of attack buildup, which is the object of the wind-up tracking turn.

Subsonic and Supersonic Constant Angle of Attack Tracking:

Data and pilot comments from the wind-up tracking turns will enable the engineer to determine which combinations of angle of attack and Mach number merit further and more extensive evaluation. This evaluation can be pursued using a constant angle of attack tracking turn at the desired Mach number. The technique for this tracking test is similar to that for the wind-up tracking turn. The tracking pilot asks the target pilot to establish a 30 degree banked turn and lines up behind him at a comfortable range (1,000-1,500 feet). When data and the gun camera have been turned on, the tracker clears the target to establish his turn at the desired angle of attack and Mach number. While the target slowly increases angle of attack to achieve the desired conditions, the tracker moves the target aircraft to a position on the edge of the reticle. When the target is at the desired angle of attack and Mach he notifies the tracker. When the tracking pilot is ready, he activates the data correlation switch (if available), moves the pipper to the target as rapidly as possible and begins to track. After tracking for 20 seconds or more (at maximum angle of attack this may prove difficult), the task may be terminated.

If the engineer wishes to evaluate the effect of large perturbations on the pilot's ability to precisely track the target, rapid and essentially constant-g barrel-rolling reversals of the direction of turn may be incorporated into the constant angle of attack tracking turns. For example, a rolling reversal would be sandwiched between two constant angle of attack tracking maneuvers. These reversals are performed at about combat break rate.

Some of the problems encountered in wind-up tracking turns are also common to constant angle of attack tracking turns, particularly at high angle of attack. The altitude sacrificed to maintain Mach number can be considerable (for an F-4, 3,000 to 5,000 feet might be lost during a 19-unit subsonic turn of 15 to 20 seconds duration and 6,000 to 8,000 feet might be lost during the same turn flown at a supersonic Mach number). A constant, high angle of attack turn may prove quite difficult to track, particularly if there is a handling qualities problem in one or more axes and heavy buffet or severe wing rock occurs. When flying supersonic turns, fuel economy can be maximized by slowing to a subsonic condition between turns to verify that the gun camera functioned properly, change film magazines, record comments, etc., and climb back to initial altitude. Since the performance of these "housekeeping" tasks requires that the pilot keep his head in the cockpit, it also proves easier to keep the target aircraft in sight at lower airspeeds.

<u>Transonic Tracking:</u>

If thrust available permits, transonic tracking can be performed in the same manner as subsonic tracking. However if insufficient thrust is available to pursue that approach, transonic handling qualities can be examined using constant angle of attack tracking turns by beginning the turn at a supersonic condition and permitting Mach number to slowly decay through the transonic region while continuing to track.

SAFETY OF FLIGHT

There is nothing intrinsically hazardous or dangerous in tracking test techniques, however a cautious and thorough approach to planning and flying a test mission is never inappropriate. Three factors deserve attention: one of the objectives of tracking test techniques is the discovery of flying qualities deficiencies in a new airplane or configuration; tracking test maneuvers will often be performed at high angle of attack; and the tracking aircraft is always in the vicinity of the target aircraft jetwash.

The first two factors can only be guarded against by caution and thorough planning and preparation. The tracking pilot must always be alert for an unexpected aircraft response, and both the target and tracking pilots must be alert during high angle of attack maneuvers. Tracking tests should never knowingly be performed at flight conditions where a stall/departure is likely.

Jetwash encounters are primarily characterized by uncontrollable rolling motion and uncomfortable impulse loading. Also, high dynamic

pressure jetwash encounters could result in severe structural loads and roll response. Care should be exercised to minimize jetwash encounters.

POINTS TO BE COVERED IN TRACKING TEST TECHNIQUES PREFLIGHT BRIEFING

Review of Maneuvers and Test Conditions:

1. Type of maneuvers to be flown and whether reversals will be included.

2. Mach number, altitude, and angle of attack (for constant angle of attack tracking) or angle of attack buildup rate (for wind-up turns) at which maneuvers will be flown.

3. Conditions at which maneuvers will be terminated: angle of attack limit, time limit, or controllability.

Review of Technique:

1. Target pilot is responsible for establishing and maintaining test conditions.

2. Maneuver should be initiated smoothly so that tracker is not immediately thrown off.

3. Initial excitation technique: To begin constant angle of attack maneuvers, move target briskly from outer ring of reticle to pipper.

4. Tracking pilot should trim his aircraft prior to the maneuver (either for straight and level flight or in anticipation of large longitudinal control forces), and must not retrim during the maneuver.

5. Tracking pilot must not use the rudder pedals: feet on the floor.

6. Tracking pilot must persistently track the precision aim point agreed to prior to the flight (e.g. tailpipe, marking on target, or other). This cannot be overemphasized.

7. Tracking pilot should attempt to maintain 1500 ±500 feet separation from target (use radar ranging or target wingspan for an approximation).

8. Duration of the maneuver should be at least 20 seconds, and more is desirable.

9. Tracking pilot must briskly move the reticle away from the target immediately after tracking is terminated.

Pilot Evaluation:

1. The tracking pilot should voice his impressions of the task and flying qualities during and/or immediately after each

maneuver. A Cooper-Harper rating should be made as soon as possible, either in flight or during post-flight debriefing.

2. Particular aspects of flying qualities or task performance to which the tracking pilot should direct his attention.

Other Considerations:

1. Gunsight depression angle.

2. Time correlation: procedure for identing film and data records during tracking.

3. Camera or gunsight filters to be used, if any.

4. Gun camera speed.

5. Marking of film magazines for identification.

6. Check film magazine after each maneuver to assure proper functioning.

Safety:

1. Procedure for avoiding jetwash.

2. Maneuver termination procedure for angle of attack or controllability limits.

3. Approach high angle of attack maneuvers (departure region) cautiously.

POINTS TO BE COVERED IN TRACKING TEST TECHNIQUES POST-FLIGHT DEBRIEFING

General Pilot Comments and Impressions of Flight:

Discussion of Each Maneuver:

1. Were the test conditions met? If not, in what way were they different (e.g. altitude had to be sacrificed to maintain Mach number, Mach number was slightly low, angle of attack was slightly high, etc.)?

2. Was the tracking aircraft trimmed for straight and level flight prior to the maneuver?

3. Did the tracking pilot retrim during the maneuver?

4. Was target-tracker separation maintained? What was the separation?

5. Did the tracking pilot use the rudder pedals?

6. Was the agreed precision aim point used?

7. Was the aim point <u>persistently</u> tracked? Was the pipper ever allowed to float?

8. Was jetwash encountered?

9. Pilot comments and impressions of task performance and aircraft flying qualities.

10. Cooper-Harper rating of flying qualities for the maneuver, based on step by step progress through the Cooper-Harper rating scale (figure 18).

11. What flying qualities improvements would be most helpful (e.g. reduced adverse yaw, improved short period damping, lighter stick, etc.).

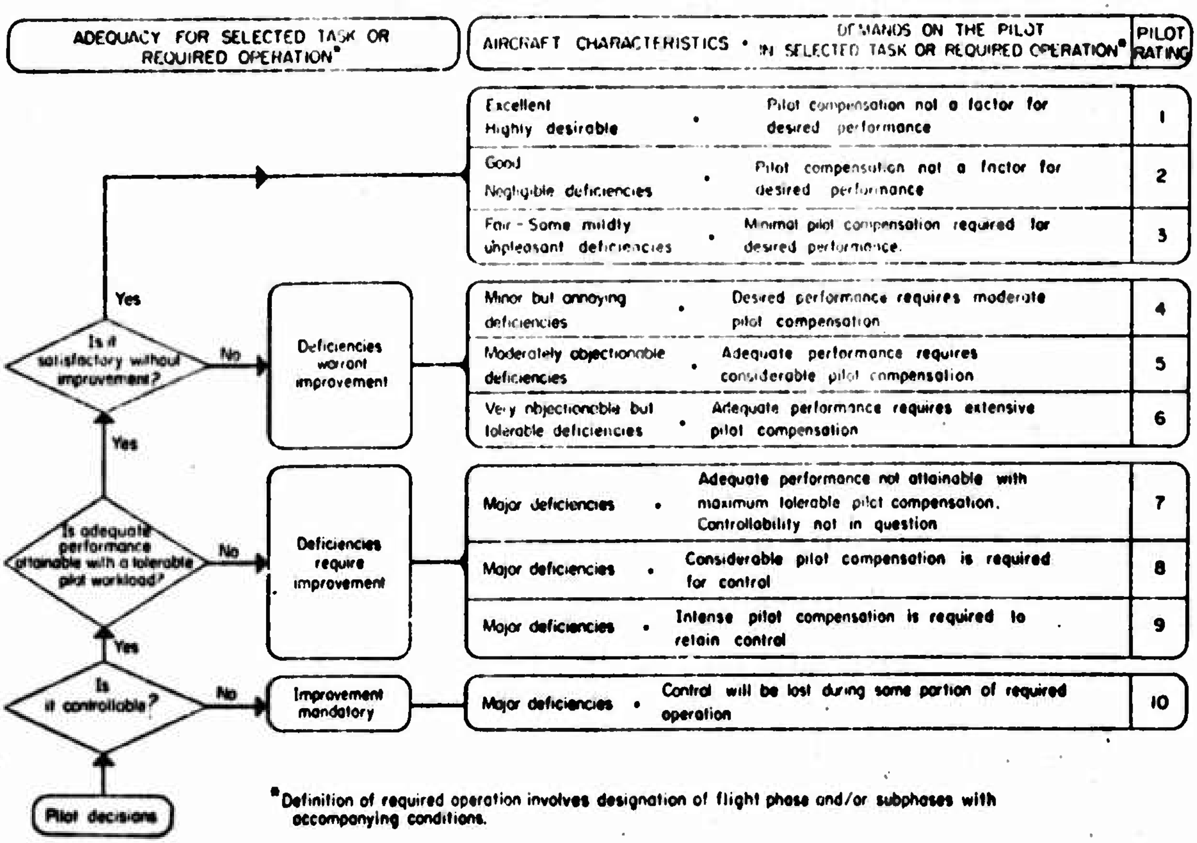

Figure 18. Cooper-Harper Rating Scale

DATA AND RELATED CONSIDERATIONS

Three sources of data are required to discover, isolate and define, and correct flying qualities deficiencies using tracking test techniques. The single most important source of data from the standpoint of discovering and isolating deficiencies are the pilot's comments, observations, and Cooper-Harper ratings. The pilot's comments and observations are also of great value in defining and scaling potential corrective measures. Further, the pilot's comments and observations are definitive in assessing the success of the corrective measures that are instituted.

The importance of the tracking pilot's contribution to the data is critical, and cannot be overemphasized or overstressed. The tracking pilot should be thoroughly briefed on the importance of his observations, comments, and ratings, and he should be alerted in advance to potential deficiencies and other points of interest to the engineer.

The best technique for gathering the pilot's comments is to record them as the test maneuver is being performed. If it is not possible to record the pilot's comments and Cooper-Harper ratings as they are made, he should be debriefed as soon as possible after the test maneuver is completed, or after the flight.

Experience indicates that there is a definite learning curve associated with tracking test techniques. A pilot who is unfamiliar with tracking test techniques or with the aircraft and its flying qualities characteristics may require several familiarization maneuvers or flights before good data and pilot comments can be obtained. This factor should be considered when planning the initial tracking test flights and when analyzing the data from these initial flights.

The two other sources of data are the gun camera film of pipper motion relative to the precision aim point, and a record of the various aircraft and control system parameters which are of interest to the engineer (airspeed, altitude, normal acceleration, stick forces, control system error signals, gain states, etc.). The gun camera film is primarily used as a supplementary record and physical measure of what the pilot is observing and reporting during the test maneuver. Taken by itself, pipper motion analysis has not been established as a reliable quantitative indication of flying qualities, but it is valuable as a supplement to the pilot's comments and observations, and as a general indicator of long-term progress in flight control system optimization. Pipper motion is secondary, i.e. supportive data and must not be mistaken for a quantitative index of flying qualities.

The record of flight and control system parameters is obtained from the normal stability and control instrumentation package aboard the aircraft. These data are important in isolating and defining the deficiencies that are discovered, and in developing corrective measures.

There are a number of important considerations pertinant to acquiring and processing these data. One of the most important of these considerations is the requirement for an accurate means of time correlating all three data sources, i.e. the pilot, the gun camera, and the instrumentation package. The engineer, in his post flight analysis of flying qualities, the flight control system, and pilot comments, will want to know what the control system and pipper were doing at any given time during the maneuver, and what the corresponding pilot comments and flight conditions were.

This can be accomplished relatively simply and effectively in the following manner. The pilot may be provided with a data correlation switch which he will activate immediately he initiates tracking (including any initial perturbation technique). Activating this switch will in turn activate an identification light in the gun camera (thus physically marking the film) and a signal trace in the data system. When the pilot

terminates his tracking effort he will immediately release, or deactivate the data correlation switch. In this way the engineer will be able to see, in each source of data, precisely where tracking began and ended. If the instant of time when each frame of gun camera film is exposed is also recorded (by recording camera shutter trip), the engineer will be able to closely associate pipper motion with pilot comment and flight control system action.

If a data correlation switch is used, it will be convenient to place the switch so that it can be activated by depressing a trigger located on the stick-grip. Locating this switch other than on the stick-grip, or perhaps the throttles, will require the pilot to divert his attention into the cockpit (to locate and actuate the correct switch) at a critical juncture in the task, and will therefore make it less likely that the beginning and end of tracking will be precisely identified.

If a data correlation switch is not used, the data may be successfully correlated to within 0.1 seconds by comparing time histories of elevation pipper error with time histories of normal acceleration, angle of attack, or pitch rate.

The installation of the gun camera is another important consideration. The camera should not obstruct the pilot's view and it must be firmly and securely mounted. During buffet, particularly during the heavy buffet associated with high angle of attack tracking, a camera which uses a long, or periscoping lens assembly) will vibrate excessively, causing the exposed film to be blurred. The camera must be easily accessible so that the pilot can readily change film magazines and diagnose simple operating problems (jammed or stripped film, etc.).

Sun and cloud background are important considerations in acquiring gun camera data. If the sun is too low it will wash out the reticle and temporarily blind the pilot when the target aircraft passes through its vicinity. Clouds and dense haze can also wash out the reticle, although proper gunsight and camera filtering can alleviate this problem to a limited extent. An orange filter (rather than the standard issue red filter) on the gunsight, to produce an orange reticle, plus a haze filter on the gun camera have produced good results. This arrangement makes it easier for the pilot to see the reticle against the clouds and makes it easier to score the gun camera film.

The importance of properly identifying and processing the gun camera film is obvious. The personnel who are responsible for loading and processing the film must be briefed on the importance of their job. Improperly loaded magazines which jam or strip the film can cost the engineer considerable valuable data and flight time. The same is true of improperly processed film, or film that is "clipped" (leader or trailer cut off) during processing.

An effective technique for identifying the film is to impress an identifying mark or number onto the film leader with a ball point pen after the film has been loaded into the magazine. The film processing personnel must be alerted to this procedure and reminded not to cut the leader from the exposed roll of film. It would be advantageous to use one or more additional means of identifying the film in case one means fails or verification is required.

A fixed (i.e. non-computing) gunsight must be used in tracking test techniques. Using a fixed gunsight eliminates the possibility that extraneous pipper motion will be introduced by coupling of the aircraft and computing gunsight dynamics. It is fundamental to tracking test techniques that all of the observed pipper motion must be motion induced by the tracking pilot's control inputs.

The gunsight pipper depression angle should be as nearly aligned with the roll axis as possible to reduce pendulum effect and keep the tracking aircraft out of the target's jetwash during the tracking tests. If a large depression angle proves necessary, care should be taken to assure that the reticle remains within the camera picture frame. A rough check of this can be accomplished on the ground by removing the film magazine from the camera, opening the shutter, and viewing the reticle through the camera. Test film shot on the ground will confirm the position of the reticle in the frame.

Appendix C

GUN CAMERAS AND FILM HANDLING PRECAUTIONS

Two gun cameras were used during the tracking test techniques studies: a Millikan DBM-2 and a Photosonics KB-26A.

The manner of installation of the Millikan camera (figure 19) proved to be a problem. The camera was mounted above the instrument panel sun shroud and to the right of the aircraft centerline. The camera was aimed at a right angle to the direction of flight so that a mirror assembly was required to photograph through the reticle. This assembly was mounted on the end of a six inch tube which extended from the camera lens to a point just aft of the gunsight combining glass. This installation arrangement caused considerable picture blurring during buffet.

Additionally, the Millikan camera either stripped the film, jammed, or otherwise failed to operate the majority of the time, particularly at g levels of 4 g and above. And on those occasions when the camera operated correctly, the film magazine often fell out, again particularly at the higher g levels. For these reasons, it became necessary to carry ten film magazines for each mission and to check the magazine in use after each tracking test for signs of failure.

The Photosonics KB-26A installation (figure 20) proved more satisfactory, although some problems were encountered as a result of the film used. Conventional 16 mm film was used (rather than the thinner mylar based 16mm film which can also be used and which permits loading an extra fifteen feet of film in a standard magazine). The conventional film was coated with a substance which left deposits in the camera, often plugging the tracking event light (data time correlation) orifice and eliminating the tracking correlation trace on the film. Additionally the Photosonics film magazines were occasionally loaded with film incorrectly, resulting in jamming or stripping of the film. Six magazines were carried in flight to minimize the impact of this latter difficulty.

One of the more frustrating and troublesome problems encountered during this program was the difficulty of establishing and maintaining the identity of each role of film throughout the exposure and developing process. This made it difficult and at times impossible to match the pilot comments and oscillograph data with the filmed tracking sequence. The solution which eventuated and was found most satisfactory was to impress an identifying number onto the film leader with a ball point pen after the film had been loaded into its magazine. The film processing personnel were alerted to this procedure and asked (and reminded often) to be certain that no film leader was cut from the roll. In this manner the film was permanently identified, thus eliminating correlation difficulties.

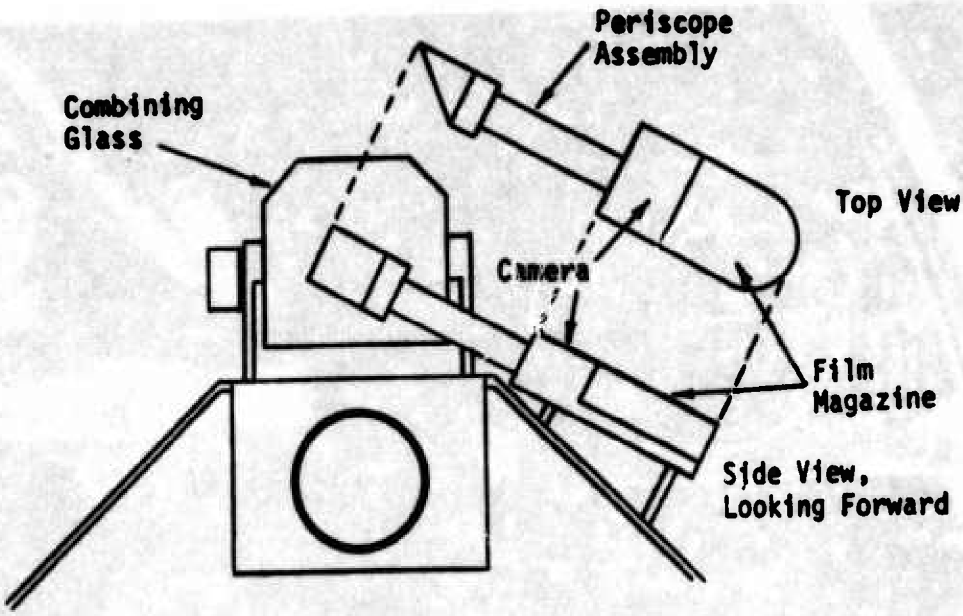

Figure 19. Millikan DBM-2 Gun Camera Installation Schematic

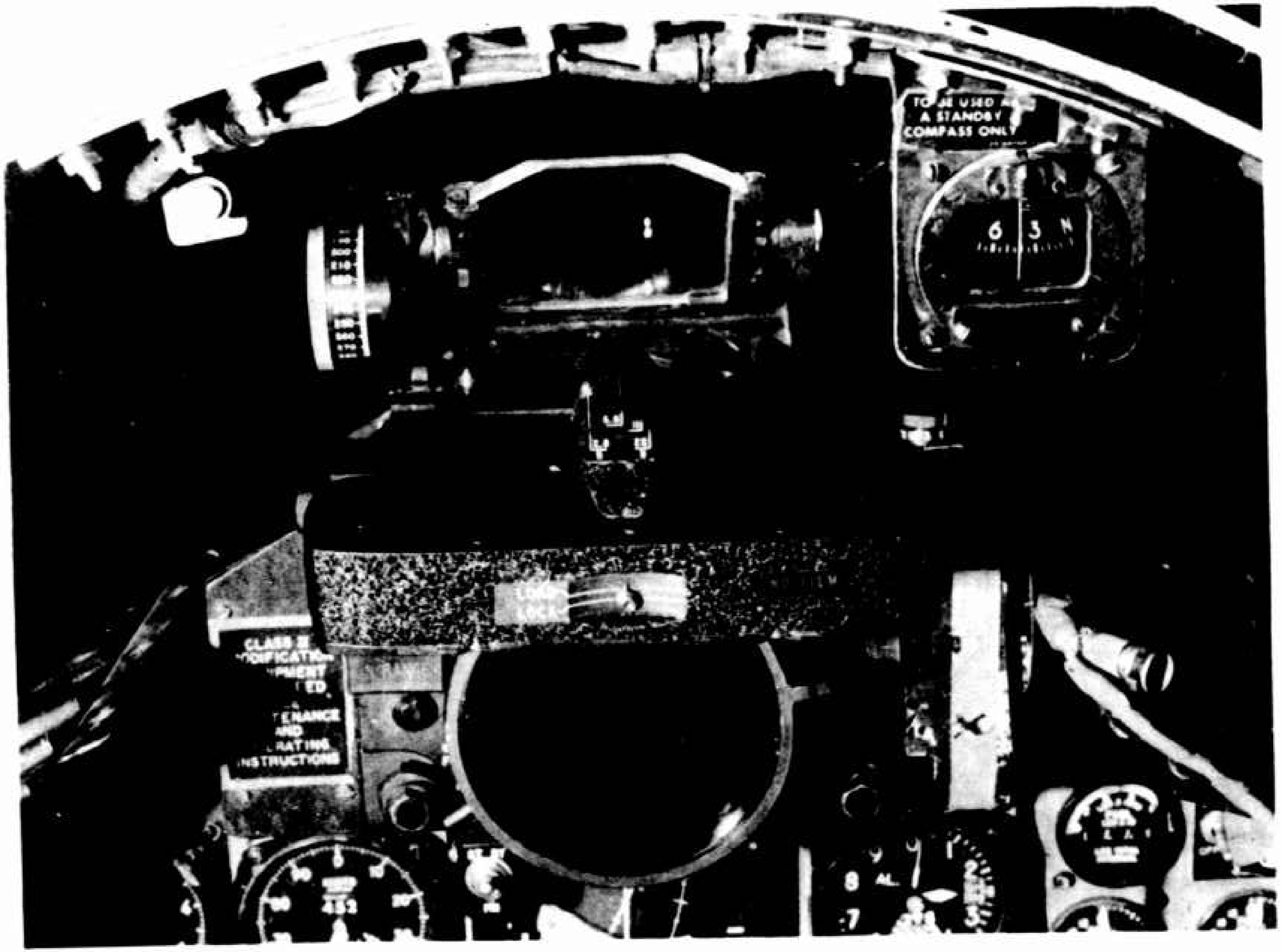

Figure 20. KB-26A Gun Camera Installation

Appendix D

TRACKING TEST TECHNIQUES PLOTTING PROGRAM

INTRODUCTION

In order to present the tracking data acquired during this study in a useful form, a CDC 6500 Computer Program was developed which calculated many pertinent parameters and presented this data using Cal-Comp plot routines. This appendix defines the computer program used to analyze the data and to make the Cal-Comp plots of tracking data.

Subsequent to this study, other programs have been written and are also being used to analyze and present tracking test techniques data.

GENERAL DESCRIPTION

Data Collection:

The raw data was collected by means of gun camera film. The film was taken on a Millikan DBM-2A gun camera through flight 26; a modified Photosonics KB-26A gun camera was used on subsequent flights. During a test run, the pilot depressed the gun trigger to identify the data gathering time period. This activated an internal gun camera light which exposed the film edge. Also, it activated an event channel on the oscillograph recorder and a light in the photopanel. This served to correlate the gun camera film with the photopanel film and the oscillograph.

Data Reading:

The Telecomputing 29A Cinetheodolite Film Reading System was used to score the gun camera film. It was decided to read every fourth frame in scoring the film thus giving a data point every one-sixth of a second. Since the reticle pipper was the zero point for all reading, the reader cross-hairs were first placed on the pipper and the zero button pushed. The film reader cross-hairs were then placed on the target tracking point (the same point on the target aircraft that the pilot used for tracking, usually an engine tailpipe), the read button pushed, and an IBM card punched giving the x and y coordinates of the target in relation to the pipper zero and data point number.

Data Computation:

The punched cards were then combined with a header card which contains flight information and constants. (The information on the header card and the data cards are shown in figure 21.) All of these cards were then used with the CDC 6500 Tracking Test Techniques Computer Program (Flowchart, figure 22; Computer FORTRAN Printout, figure 23) which produced a hard copy printout (figure 24) and a magnetic plot tape.

The major calculations made are the computations for RMS error, time on target, percentage of points on target, and percentage of all

points within different error ranges. These computations are explained in figures 22 and 23.

Cal-Comp Plots:

The magnetic plot tape was used with the Cal-Comp Plotter to achieve the final plots. The following is an explanation of these plots.

Pipper Position vs Target.

This plot (figure 1A) shows the position of the pipper with respect to the target tracking point. The target tracking point is the zero mil point of the plot. It also shows the relative motion of the tracking pipper to the target point by the small arrow printed every fifth data point. The interval at which the arrows are printed can be varied by one statement in the computer program. The Cal-Comp routine is explained in figure 23.

Error vs Angle of Attack.

Figure 1C presents the relation of lateral, longitudinal and total RMS error to the angle of attack of the tracking aircraft. For the wind-up turns, the RMS errors are calculated from a data range of one unit angle of attack; i.e., the data present at ten units are obtained from a data range of ten to eleven units. The Cal-Comp routine is explained in figure 23.

Error vs g.

Figure 1B shows the relation of lateral, longitudinal and total root mean squared error to the normal acceleration (g) of the tracking aircraft. For the wind-up turns, the RMS errors are computed from a data range of +0.5 g's about the g value presented; i.e., the data presented at 3.0 g's was obtained from a data range of 3.0 to 3.4 g's and the data for 3.5 g's was obtained from a data range of 3.5 to 3.9 g's. Normal acceleration data is obtained through correlation with another data source (oscillograph in the case of F-4C S/N 63-7409). In order for this plot to be plotted, a real number other than zero has to be punched into columns 78, 79, or 80 of the header card. If a zero is punched in or if left blank, this plot will not be plotted. The Cal-Comp routine is explained in figure 23.

Error Time History.

Figure 1D is a plot of the vertical, horizontal and total error between the tracking pipper and the aim point on the target versus time. The Cal-Comp routine is explained in figure 23.

Percent Tracking Time vs Error.

Figure 1E presents the percentage of the total tracking time that the pipper was within a given error range. The two lines in this plot show both lateral and longitudinal error. The Cal-Comp routine is explained in figure 23.

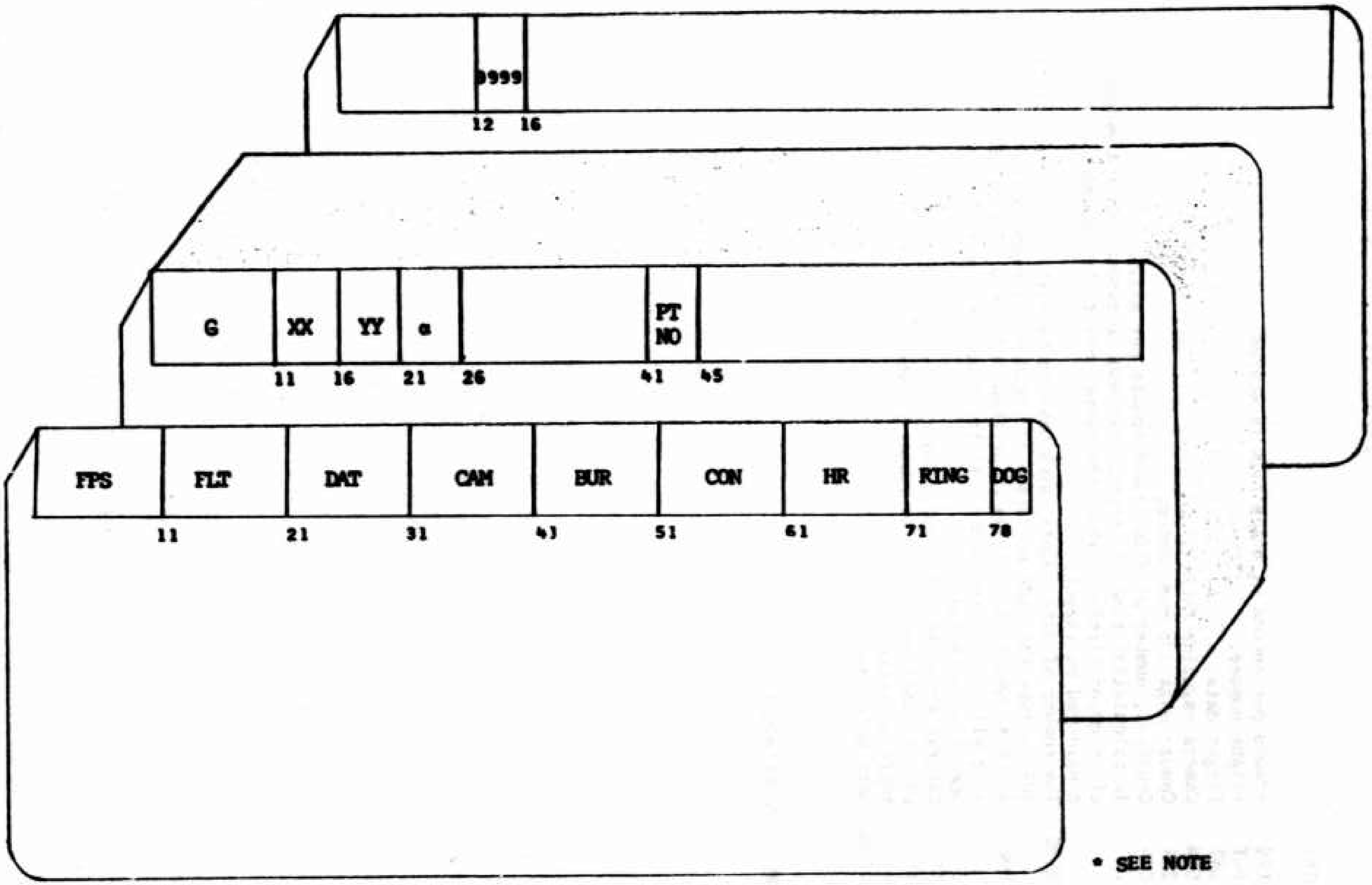

Figure 21 Plotter Program Deck Setup

• NOTE:

FPS	Frames per second at which film is scored.
FLT	Flight number.
DAT	Flight data.
CAM	Camera magazine number.
BUR	Camera magazine run number.
CON	Constant, number of film reader counts per mil.
HR	In calculating time on target, this number represents the radius of an error circle in which the pipper has to be in order to be considered on target.
RING	The number of data points which have to be within the error circle (HR) before the time on target is begun to be calculated.
DOG	If this number is anything other than zero, the plot of ERROR vs g will be plotted along with the other four plots.
G	Normal acceleration.
XX	Lateral error in film reader counts.
YY	Longitudinal error in film reader counts.
α	Angle of attack.
PT NO	Data point number.

FIGURE 21 (CONTINUED)

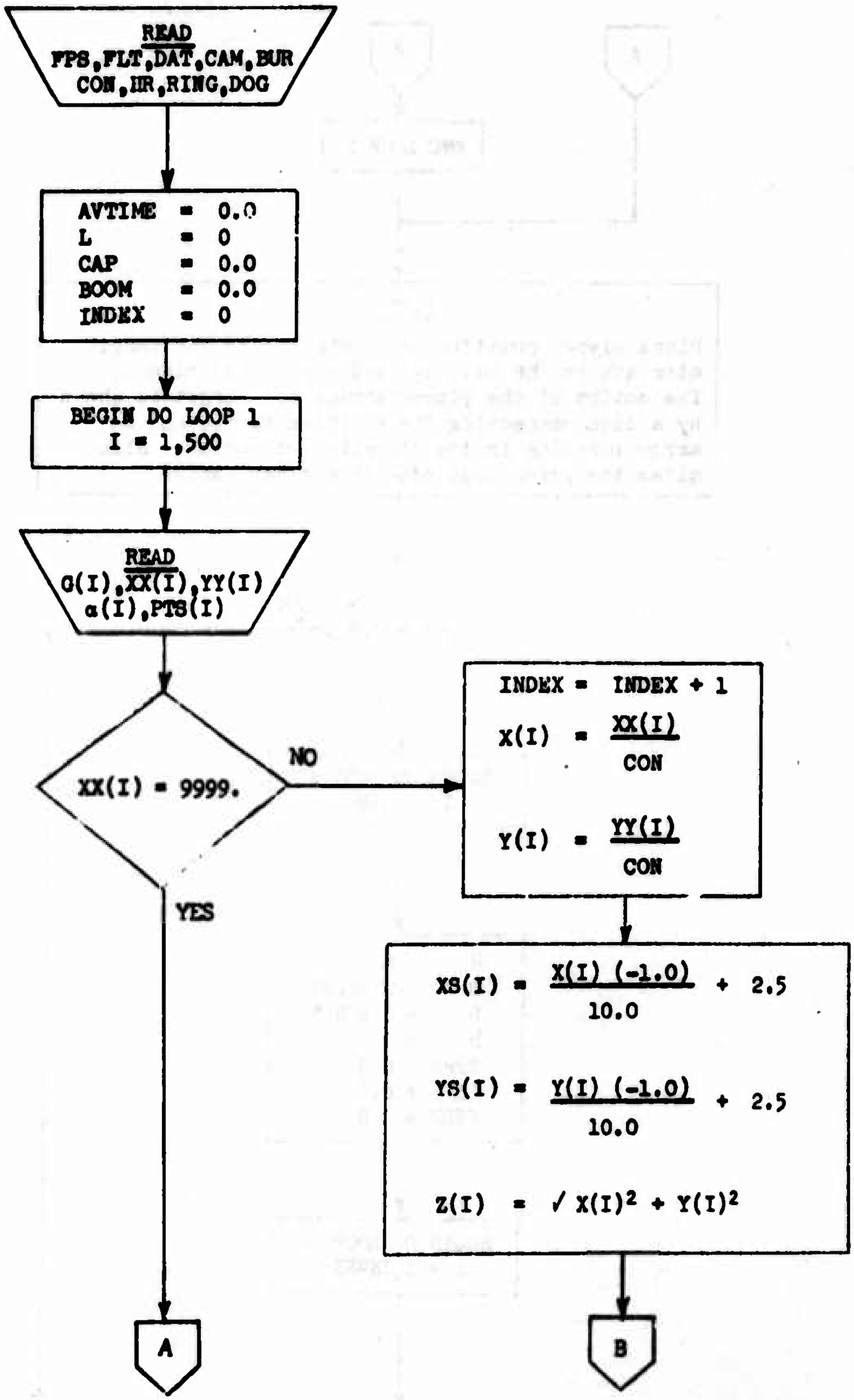

FIGURE 22 PLOTTER PROGRAM FLOWCHART

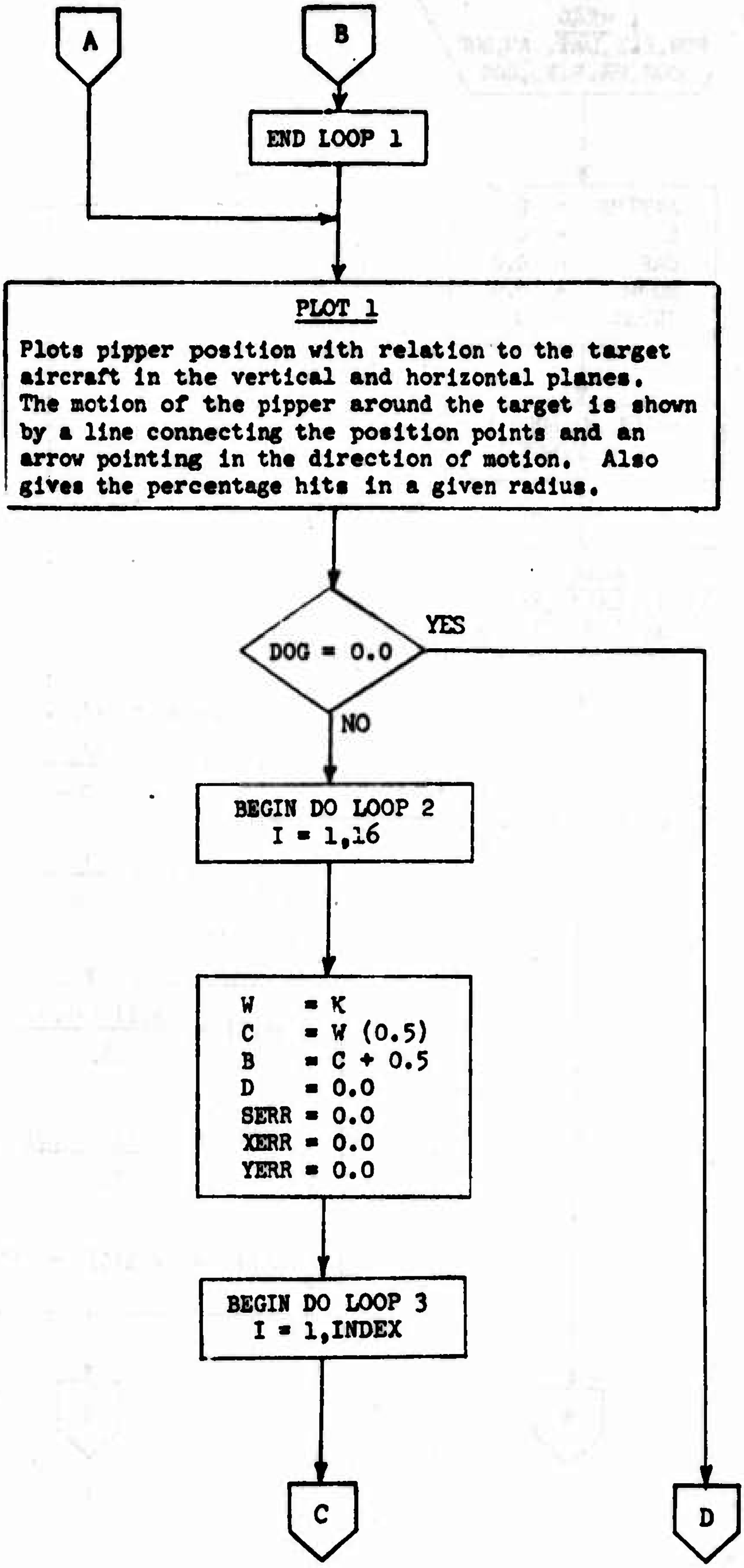

FIGURE 22 (Continued)

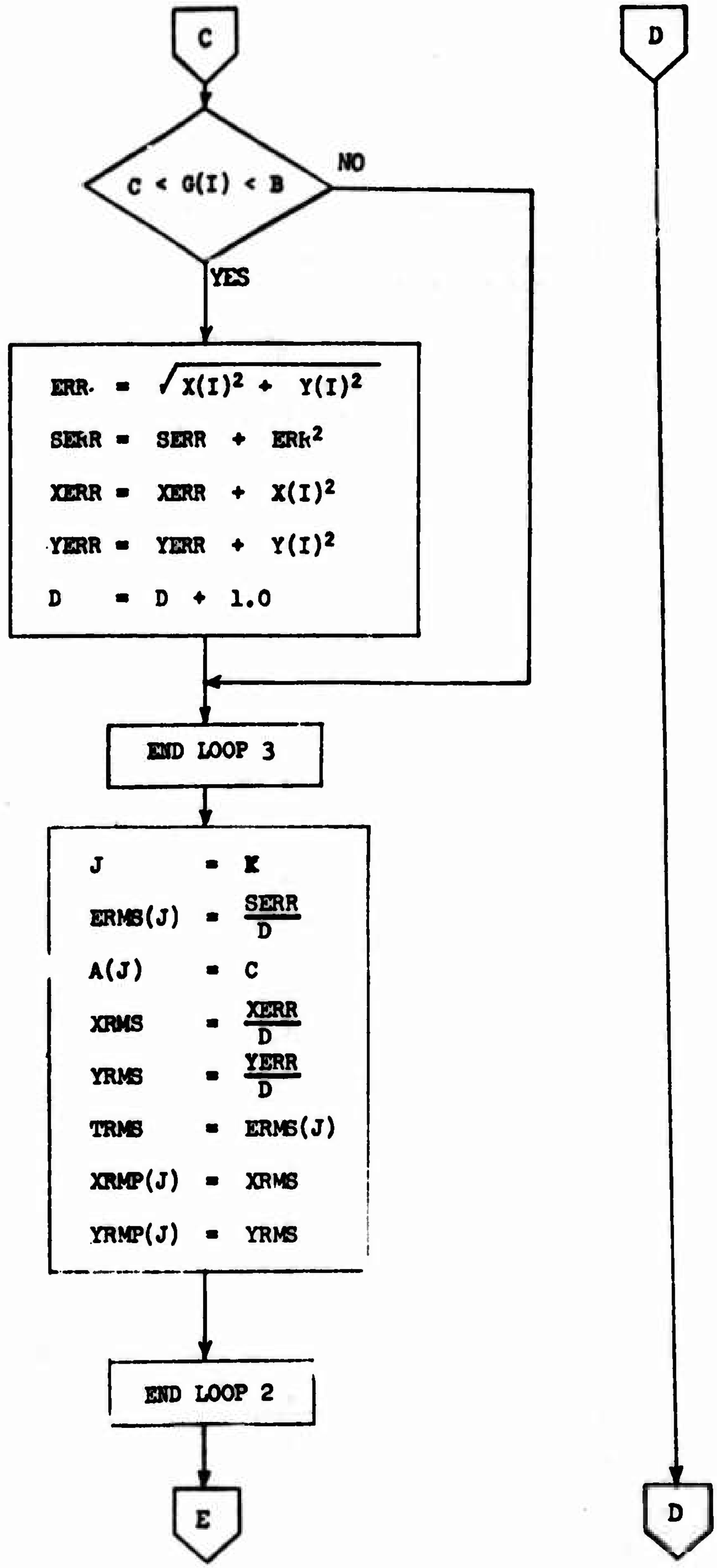

FIGURE 22 (Continued)

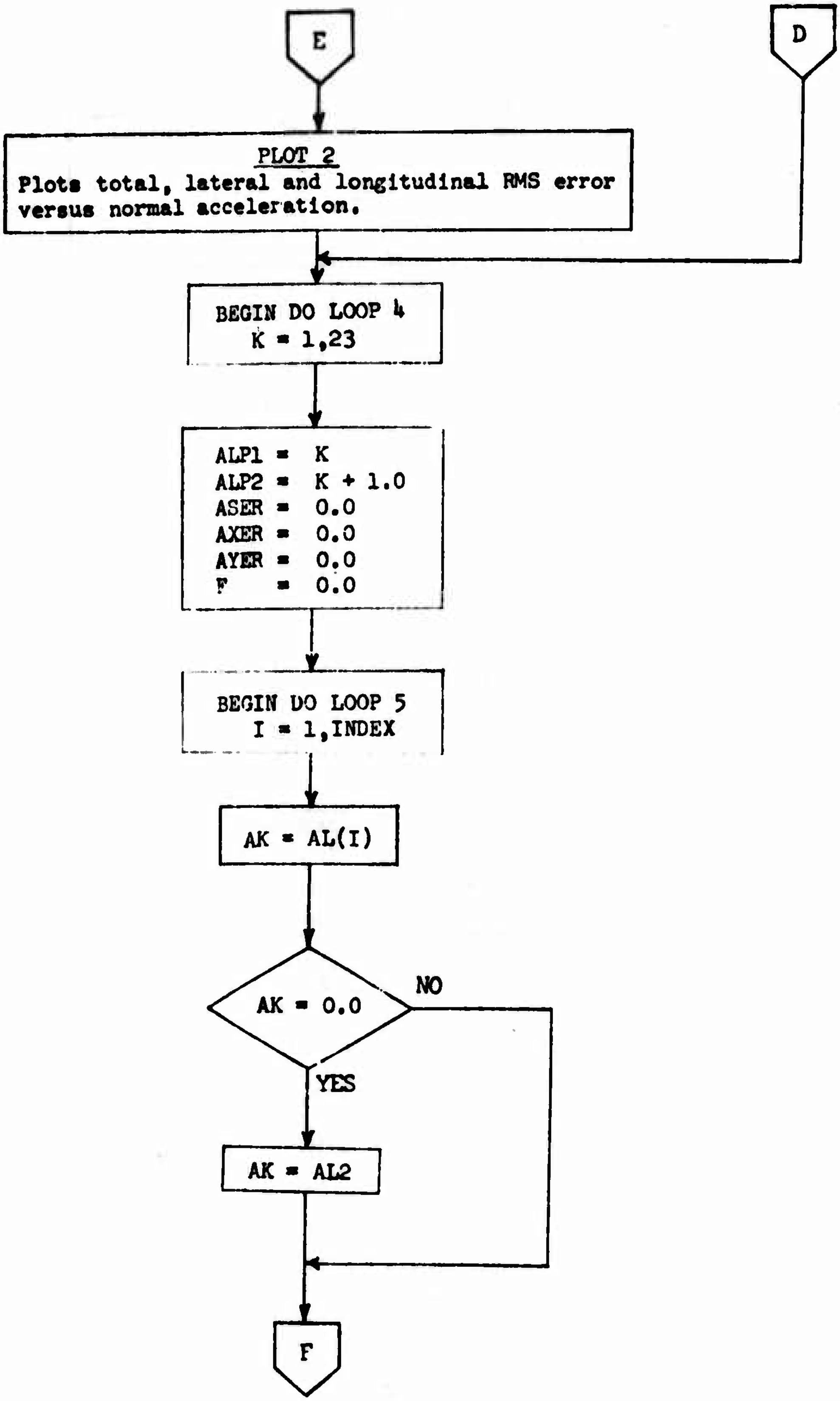

FIGURE 22 (Continued)

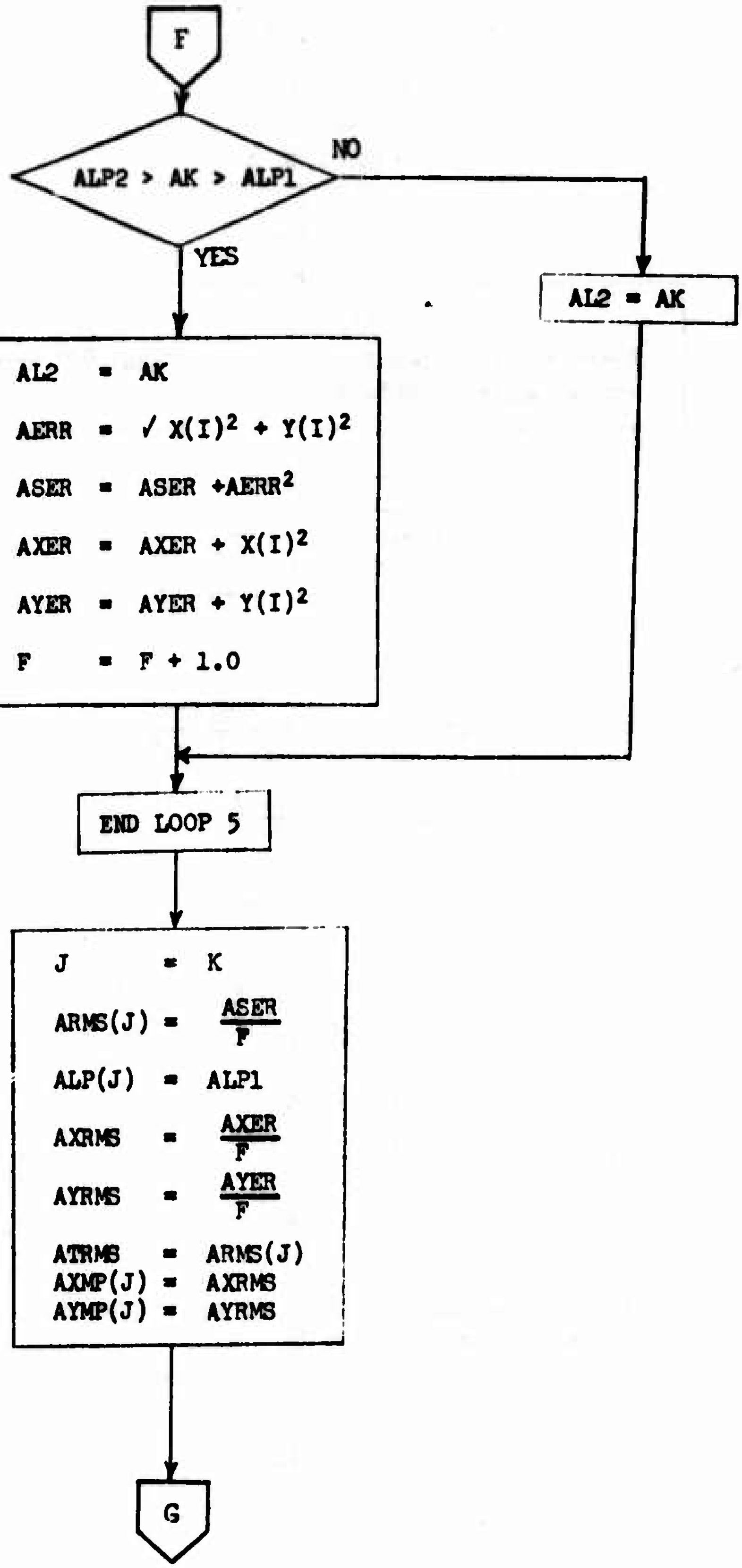

FIGURE 22 (Continued)

G

END LOOP 4

PLOT 3

Plots total, lateral, and longitudinal RMS error versus angle of attack.

BEGIN DO LOOP 6
I = 1,INDEX

$$TIME(I) = \frac{PTS(I)}{(FPS)\ (4.0)}$$

$$TOTER(I) = \frac{Z(I)}{20.0}$$

$$HORER(I) = \frac{X(I)}{20.0} + 3.0$$

$$VERER(I) = \frac{Y(I)}{20.0} + 6.0$$

END LOOP 6

PLOT 4

Plots time history of total, horizontal and vertical error of pipper versus target.

H

FIGURE 22 (Continued)

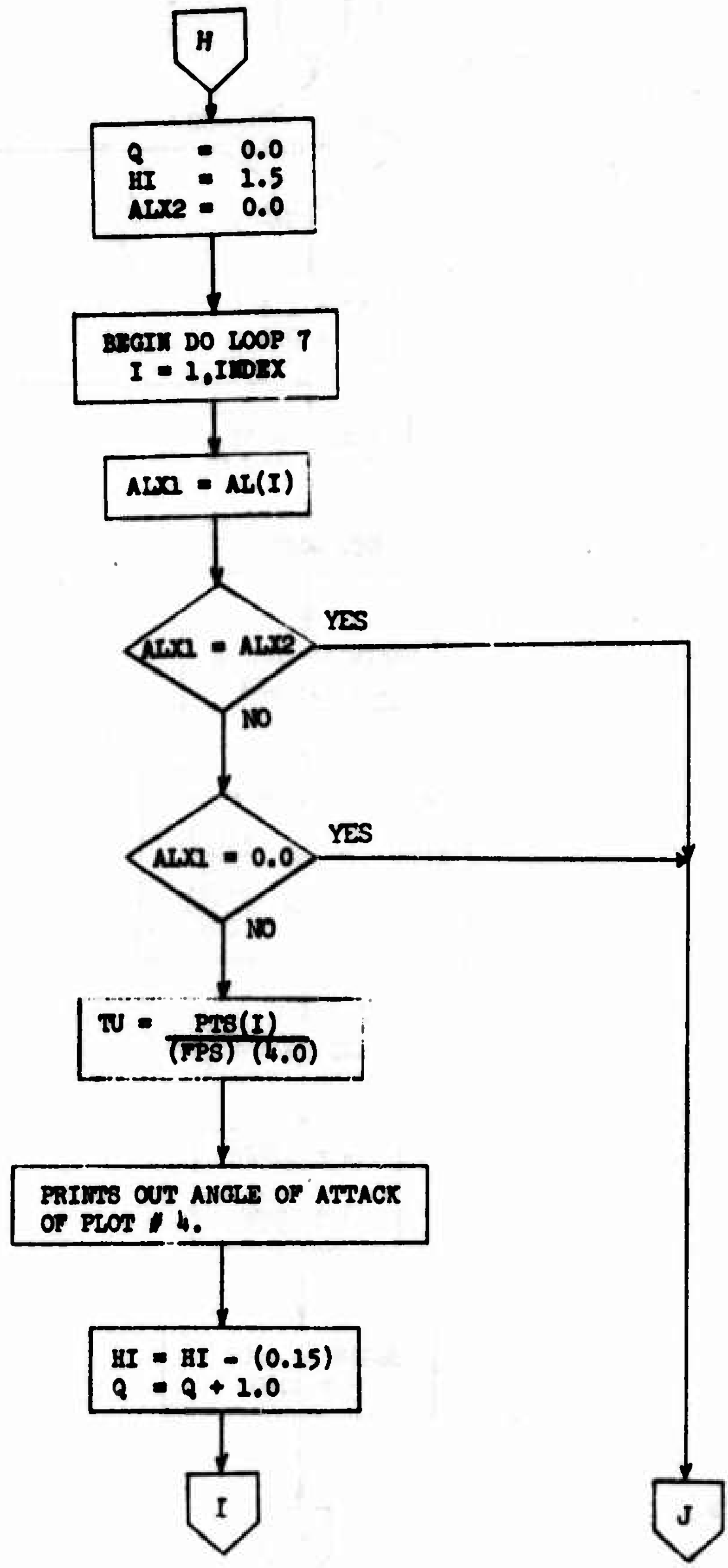

FIGURE 22 (Continued)

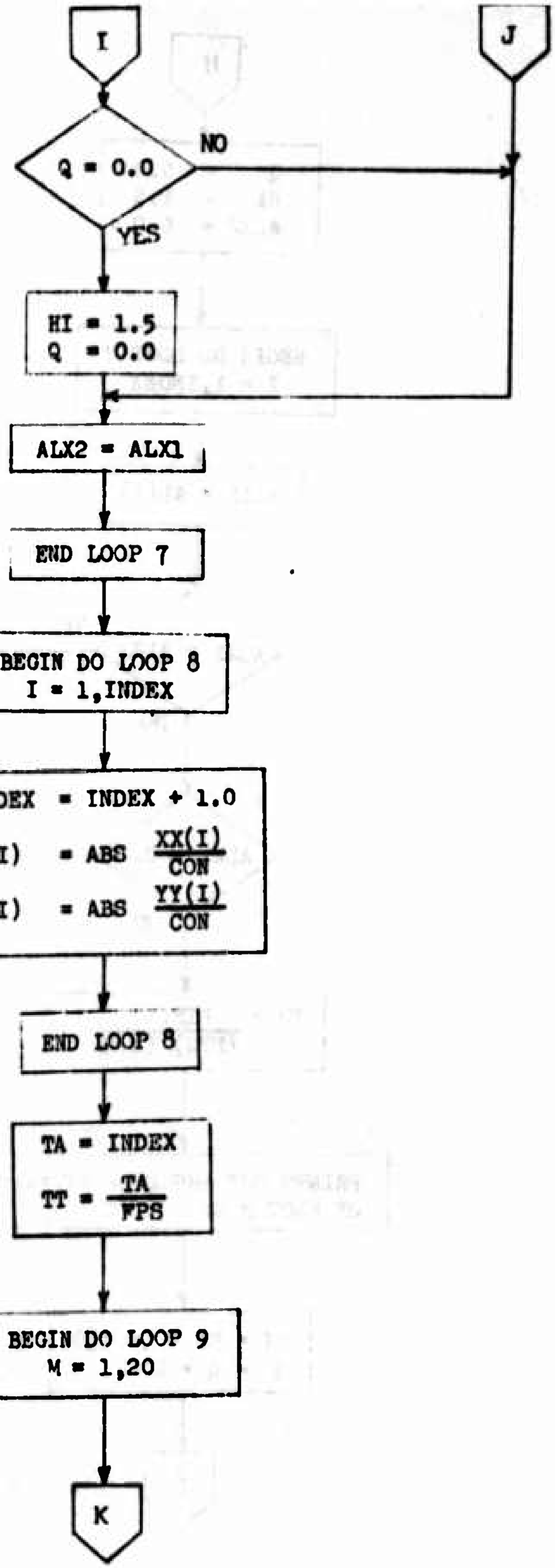

FIGURE 22 (Continued)

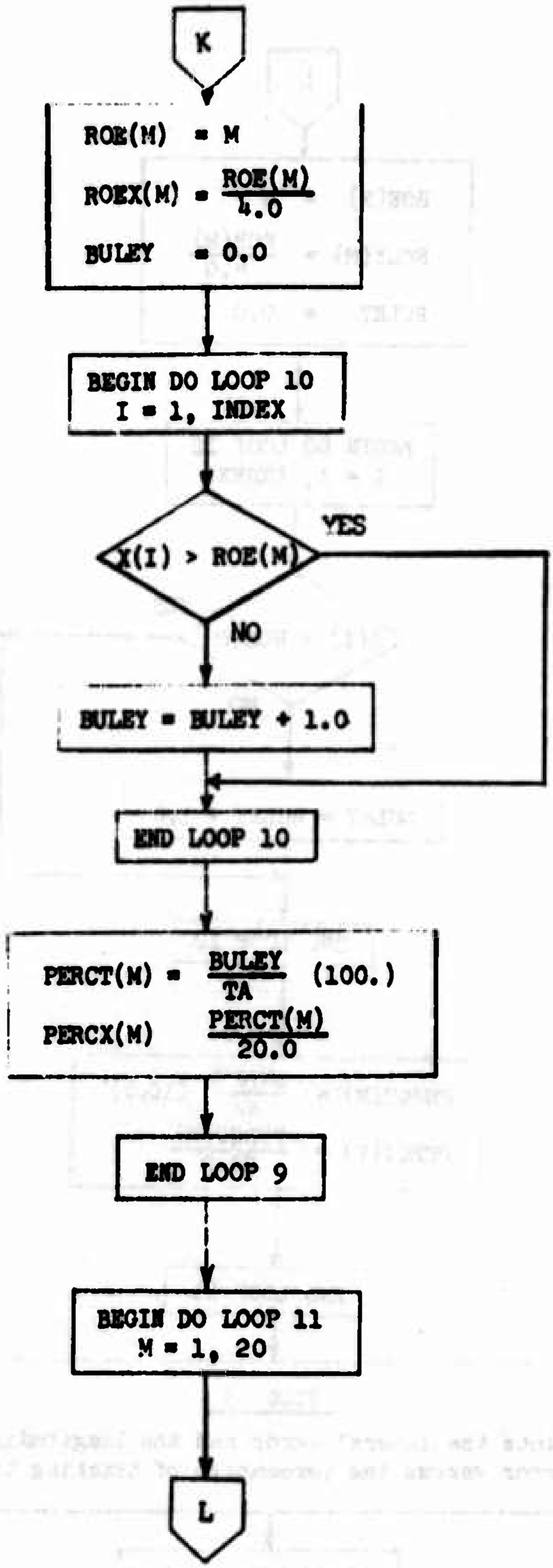

FIGURE 22 (Continued)

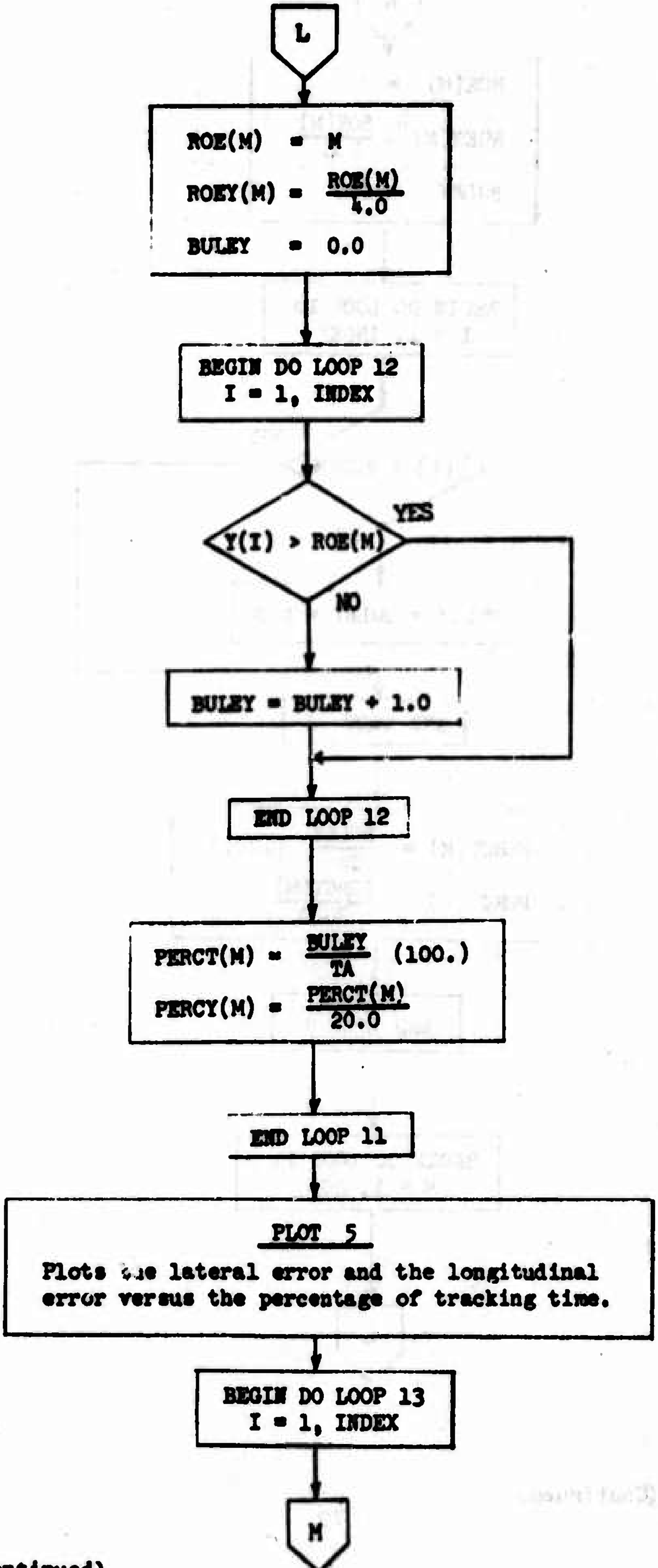

FIGURE 22 (Continued)

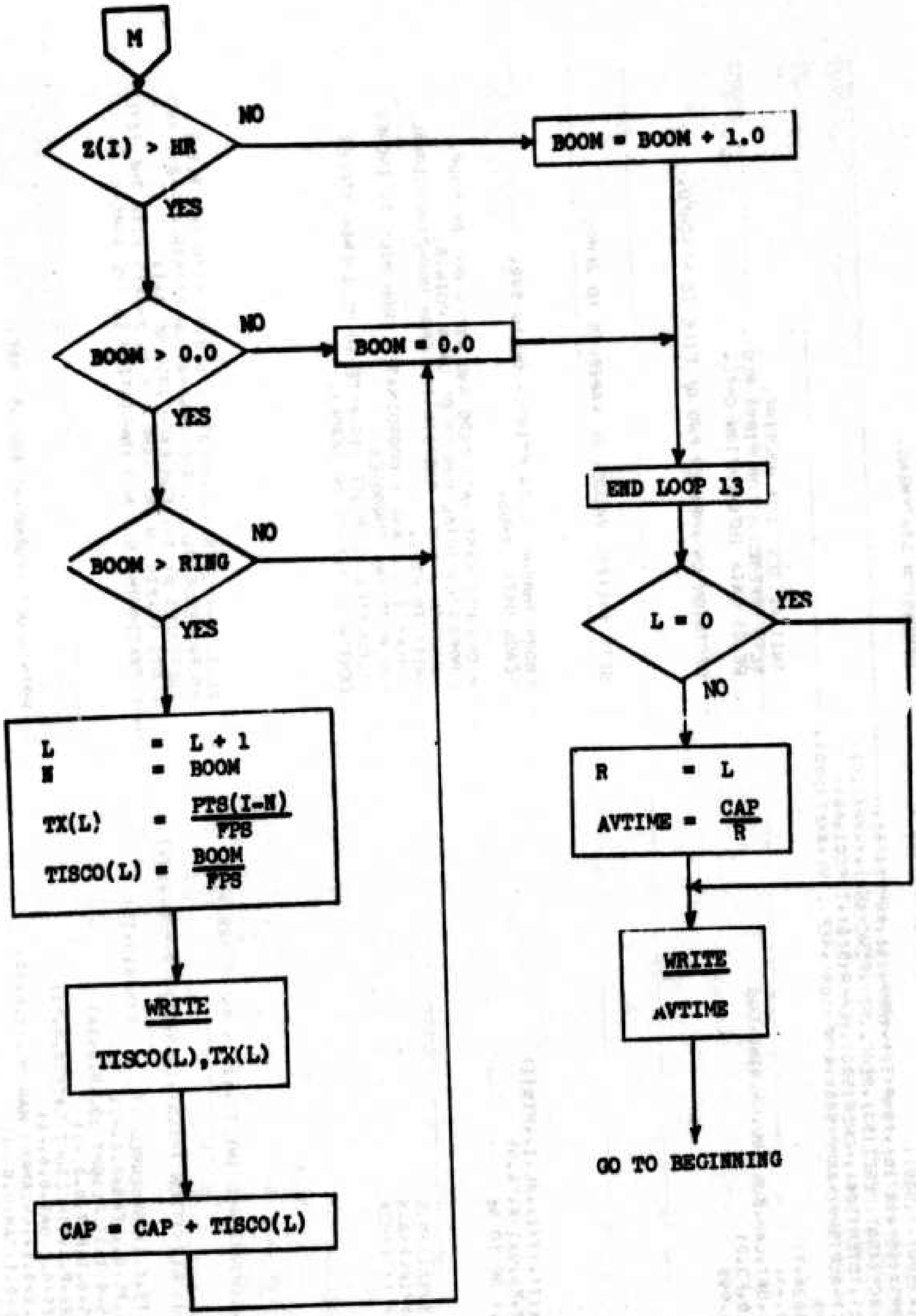

FIGURE 22 (Concluded)

FIGURE 23

PLOTTER PROGRAM FORTRAN

`DIMENSION DATA (1024),XX(500),YY(500),G(500),Z(500),TX(500),` `C XS(500),YS(500),X(500),Y(500),` `CERMS(16),A(16),ERMSX(16),AX(16),XRMP(16),YRMP(16),XRMPX(16),` `CROE(50),ROEX(50),ROEY(50),PERCT(50),PERCX(50),PERCY(50),YRMPX(16),` `CPTS(500),TIME(500),TOTER(500),HORER(500),VERER(500),TISCO(500),` `C AL(500),ARMS(500),ALP(500),AXMP(500),AYMP(500),AEF(500),AXEF(500),` `C,AYEF(500),AP(500)`	DIMENSION STATEMENT.
`CALL PLOTS(DATA,1024,7)`	INITIALIZES PLOT ROUTINE.
`CALL PLOT(2.0,3.0,-3)`	SETS REFERENCE FOR FIRST PLOT.
`200 READ(5,10)FPS,FLT,DAT,CAM,BUR,CON,HR,RING,DOG` `10 FORMAT(7F10.0,F7.0,F3.0)`	READS DATA INFORMATION CARD.
`IF(EOF(5))998,999,998` `998 STOP` `999 CONTINUE`	DECISION ON WHETHER END OF FILE IS REACHED.
`L= 0` `CAP= 0.0` `AVTIME= 0.0` `ROOM= 0.0` `INDEX= 0` `HITS= 0.0`	SETS INITIAL VALUES OF VARIBLES TO ZERO.
`DO 25 I= 1,500`	LOOPS THROUGH DATA POINTS, UP TO 500.
`READ(5,11) G(I),XX(I),YY(I),AL(I),PTS(I)` `11 FORMAT(F10.1,2F5.0,F5.0,15X,F4.0)`	READS DATA CARDS.
`IF(XX(I).EQ. 9999.) GO TO 42`	PICKS OUT LAST DATA CARD AND KICKS OUT OF LOOP.
`INDEX= INDEX + 1`	CUMMULATES TOTAL NUMBER OF DATA POINTS.
`X(I)=(XX(I)/CON)` `Y(I)= YY(I)/CON`	CONVERTS X AND Y COORDINATES FROM NON-DIMENSIONAL UNITS TO MILS.
`XS(I)=((X(I)*(-1.))/10.)+2.5` `YS(I)=((Y(I)*(-1.))/10.)+2.5`	SCALES THE X AND Y COORDINATES FROM MILS TO INCHES FOR PLOTTING PURPOSES.
`Z(I)=SQRT(X(I)**2 + Y(I)**2)`	CALCULATES ABSOLUTE DISTANCE IN MILS FROM PIPPER CENTER TO CENTER OF TARGET.
`25 CONTINUE`	
`42 CALL AXIS (0.0,0.0,15HTRAVERSE (MILS),-15,5.0,0.0,-25.,10.)`	PLOTS X-AXIS STARTING AT (0.0,0.0) WITH THE TITLE OF TRAVERSE(MILS). THE ANNOTATION STARTS AT -25. AND INCREASES BY 10. FOR EACH INCH OF AXIS.
`CALL AXIS (0.0,0.0,16HELEVATION (MILS),16,5.0,90.0,-25.,10.)`	PLOTS Y-AXIS IN THE SAME WAY AS X-AXIS WITH THE TITLE ELEVATION(MILS), AND ANNOTATION IS THE SAME ALSO.
`CALL SYMBOL (0.0,5.75,0.1,18HSCORED AT      F/S,0.0,18)` `CALL NUMBER (1.00,5.75,0.1,FPS,0.0,-1)` `CALL SYMBOL (0.0,5.5,0.1,10HFLIGHT NO.,0.0,10)` `CALL NUMBER (1.1,5.5,0.1,FLT,0.0,-1)` `CALL SYMBOL (0.0,5.25,0.1,11HFLIGHT DATE,0.0,11)` `CALL NUMBER (1.1,5.25,0.1,DAT,0.0,-1)` `CALL SYMBOL (3.25,5.5,0.1,14HCAMERA MAG NO.,0.0,14)` `CALL NUMBER (4.6,5.5,0.1,CAM,0.0,-1)` `CALL SYMBOL (3.25,5.25,0.1,9HBURST NO.,0.0,9)` `CALL NUMBER (4.25,5.25,0.1,BUR,0.0,-1)`	PRINTS OUT LEGEND AT TOP OF PAGE.

FIGURE 23 (CONTINUED)

```
      CALL SYMBOL (-0.5,-1.50,0.15,6HFIGURE,0.0,6)
      CALL SYMBOL (1.2,-1.50,0.15,33HPLOT OF PIPPER POSITION VS TARGET.
     C0.0,33)
      CALL PLOT(1.5,2.5,3)
      CALL PLOT(3.5,2.5,2)
      CALL PLOT(2.5,3.5,3)
      CALL PLOT(2.5,1.5,2)
      I=1
      CALL SYMBOL (XS(I),YS(I),0.1,14,0.0,-1)
      CALL PLOT (XS(I), YS(I), 3)
      DO 100  I=2,INDEX
      AA=XS(I)-XS(I-1)
      IF(AA.LT.0.000000001 .AND.AA .GT.-0.000000001)AA=0.000000001
      BB=YS(I)-YS(I-1)
      THETA=ATAN(BB/AA)
      THETA=THETA*(57.3)
      IF((XS(I)-XS(I-1)).GT.0.0.AND.(YS(I)-YS(I-1)).GT.0.0)  GO TO 400
      IF((XS(I)-XS(I-1)).LT.0.0.AND.(YS(I)-YS(I-1)).GT.0.0) GO TO 401
      IF((XS(I)-XS(I-1)).LT.0.0.AND.(YS(I)-YS(I-1)).LT.0.0) GO TO 402
      IF((XS(I)-XS(I-1)).GT.0.0.AND.(YS(I)-YS(I-1)).LT.0.0) GO TO 403
  400 THETA=THETA + 0.0
      GO TO 404
  401 THETA= 180.0 + THETA
      GO TO 404
  402 THETA=THETA + 180.0
      GO TO 404
  403 THETA= 360.0 + THETA
      GO TO 404
  404 THETA=THETA - 90.0
      IF(THETA .LT. 0.0) GO TO 500
      GO TO 405
  500 THETA= 360.0 + THETA
  405 CALL PLOT (XS(I),YS(I),2)
      IF(MOD(I,5).EQ. 0) CALL SYMBOL(XS(I),YS(I),0.1,6,THETA,-2)
      CALL PLOT (XS(I),YS(I),3)
  100 CONTINUE
      IF(DOG .EQ. 0.0) GO TO 47
      CALL PLOT(8.0,0.0,-3)
      DO 20  K=1,16
      W=K
      C=W*0.5
      B=C+ 0.5
      D= 0.0
      SERR= 0.0
      XERR= 0.0
      YERR= 0.0
      DO 15  I= 1,INDEX
      IF(G(I).GE. C .AND. G(I) .LT. B) GO TO 16
      GO TO 15
```

PRINTS OUT TITLE OF PLOT AT BOTTOM OF PAGE.

PLOTS A CROSS IN THE CENTER OF THE PAGE

SETS I EQUAL TO ONE.
PRINTS OUT THE SYMBOL, , FOR THE FIRST DATA POINT.
PUTS PLOTTER PEN BACK TO FIRST POINT.
LOOPS FROM SECOND TO LAST DATA POINT.

TAKES A POINT AND ITS PRECEDING POINT AND CALCULATES THE ANGLE THAT A LINE BETWEEN THE TWO POINTS MAKE WITH THE X=AXIS.

DETERMINES IN WHICH QUADRANT THE LINE IS.

ACCORDING TO WHICH QUADRANT THE LINE IS IN,CALCULATE THE TOTAL ANGLE.

TELLS PLOTTER TO MOVE TO AN X AND Y POSITION, ACCORDING TO VALUE OF I, WITH THE PEN DOWN THUS DRAWING A LINE BETWEEN THE POINTS.
AT EVERY FIFTH POINT,TELLS PLOTTER TO PUT AN ARROW ON THAT POINT AT THE ANGLE CALCULATED IN LINE 68-79. THIS SHOWS DIRECTION IN WHICH LINE IS MOVING.
TELLS PLOTTER TO MOVE BACK TO POINT DEFINED IN LINE 80 WITH PEN UP.

IF DOG EQUALS ZERO, G LOAD PLOT IS NOT DONE. IF OTHER THAN ZERO PLOT IS DONE.
TELLS PLOTTER TO MOVE ALONG THE X-AXIS FOR 8 INCHES WITH THE PEN UP AND ESTABLISH A NEW REFERENCE POINT.
LOOP THROUGH THE G LOAD RANGE.
CHANGES FIXED POINT NUMBERS TO FLOATING POINT NUMBERS.
CALCULATES UPPER AND LOWER LIMIT OF G LOAD FOR THE PARTICULAR TIME THROUGH THE LOOP.

ESTABLISHES INITIAL VALUES OF ZERO.

LOOP TO DETERMINE THE POINTS AT A PARTICULAR G LOAD.
DECIDES WHICH DATA POINTS FALL WITHIN THE G LOAD RANGE.

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FIGURE 23 (CONTINUED)

```
16 ERR=SQRT(X(I)**2 + Y(I)**2)
   SERR= SERR + (ERR**2)
   XERR= XERR + (X(I)**2)
   YERR= YERR + (Y(I)**2)
   D= D+ 1.0
15 CONTINUE
   J=K                                        CALCULATES THE TOTAL, X-AXIS, AND THE Y-AXIS ROOT
   ERMS(J)= SQRT(SERR/D)                      MEAN SQUARE ERROR.
   A(J)=C
   XRMS= SQRT(XERR/D)
   YRMS= SQRT(YERR/D)
   TRMS=ERMS(J)
   XRMP(J)=XRMS
   YRMP(J)=YRMS
20 CONTINUE
   CALL AXIS(0.0,0.0,9HRMS ERROR,-9,5.0,0.0,0.,4.)
                                              PLOTS X-AXIS STARTING AT (0.0,0.0) WITH THE TITLE
                                              RMS ERROR. THE ANNOTATION STARTS AT 0.0 AND INCREASES
                                              BY 4.0 PER INCH.
   CALL AXIS(0.0,0.0,22HNORMAL ACCLERATION (G),22,5.0,90.,0.,2.)
                                              PLOTS Y-AXIS STARTING AT (0.0,0.0) WITH THE TITLE NORMAL
                                              ACCELERATION (G). THE ANNOTATION STARTS AT 0.0 AND
                                              INCREASES BY 2.0 PER INCH.

   CALL SYMBOL(0.0,5.5,0.1,10HFLIGHT NO.,0.0,10)
   CALL NUMBER(1.1,5.5,0.1,FLT,0.0,-1)
   CALL SYMBOL(0.0,5.25,0.1,11HFLIGHT DATE,0.0,11)
   CALL NUMBER(1.2,5.25,0.1,DAT,0.0,-1)
   CALL SYMBOL(3.25,5.5,0.1,14HCAMERA MAG NO.,0.0,14)   PRINTS OUT LEGEND AT TOP OF PAGE.
   CALL NUMBER(4.6,5.5,0.1,CAM,0.0,-1)
   CALL SYMBOL(3.25,5.25,0.1,9HBURST NO.,0.0,9)
   CALL NUMBER(4.25,5.25,0.1,BUR,0.0,-1)
   CALL SYMBOL(-0.5,-1.50,0.15,6HFIGURE,0.0,6)          PRINTS TITLE AT THE BOTTOM OF PAGE.
   CALL SYMBOL(1.2,-1.50,0.15,10HERROR VS G,0.0,10)
   DO 46  J=1,16                              LOOP TO PLOT ERROR VS. G.
   ERMSX(J)=ERMS(J)/4.0
   XRMPX(J)=XRMP(J)/4.0                       SCALES TOTAL, X-AXIS, AND Y-AXIS ERRORS FOR PLOTTING.
   YRMPX(J)=YRMP(J)/4.0
   AX(J)=A(J)/2.0                             SCALES G LOADS FOR PLOTTING.
   IF(ERMSX .EQ. 0.0) GO TO 46
   CALL PLOT(ERMSX(J),AX(J),3)
   CALL SYMBOL(ERMSX(J),AX(J),0.1,14,0.0,-1)  PLOTS TOTAL, X-AXIS, AND Y-AXIS ERRORSVERSUS G LOADS
   CALL PLOT(XRMPX(J),AX(J),3)                AND PRINT APPROPRIATE SYMBOLS FOR POINTS.
   CALL SYMBOL(XRMPX(J),AX(J),0.1,0,0.0,-1)
   CALL PLOT(YRMPX(J),AX(J),3)
   CALL SYMBOL(YRMPX(J),AX(J),0.1,2,0.0,-1)
46 CONTINUE
47 CALL PLOT(8.0,-0.5,-3)                     TELLS PLOTTER TO MOVE 8 INCHES TO THE RIGHT AND
                                              0.5 INCHES DOWN AND ESTABLISH A NEW REFERENCE POINT.
   DO 21 K=1,23                               LOOPS THROUGH COMPLETE ANGLE OF ATTACK RANGE.
   ALP1= K                                    SETS UP UPPER AND LOWER ANGLE OF ATTACK RANGES FOR
   ALP2= K + 1.                               EACH LOOP.
   ASER= 0.0
   AXER= 0.0                                  SETS INITIAL VALUES EQUAL TO ZERO.
   AYER= 0.0
   F= 0.0
   DO 22 I=1,INDEX                            LOOPS THROUGH ALL DATA POINTS.
```

FIGURE 23 (CONTINUED)

```
      AK= AL(I)
      IF(AK .NE. 0.0) GO TO 17
      AK= AL2
   17 IF(AK .GE. ALP1 .AND. AK .LT. ALP2) GO TO 24
      AL2= AK
      GO TO 22
   24 AL2= AK
```

THESE STATEMENTS ALLOW THE ANGLE OF ATTACK TO BE PUNCHED INTO A PARTICULAR DATA CARD AND THE VALUE WILL REMAIN THE SAME FOR SUCCEEDING CARDS IF THE COLUMNS ARE LEFT BLANK. IF A REAL NUMBER OTHER THAN ZERO IS PUNCHED INTO THESE COLUMNS THE VALUE OF ANGLE OF ATTACK WILL CHANGE TO THIS NUMBER.

```
   23 AERR= SQRT(X(I)**2+Y(I)**2)
      ASER= ASER + (AERR**2)
      AXER= AXER + (X(I)**2)
      AYER = AYER + (Y(I)**2)
      F = F+ 1.0
   22 CONTINUE
      J=K
      ARMS(J)= SQRT(ASER/F)
      ALP(J)= ALP1
      AXRMS= SQRT(AXER/F)
      AYRMS= SQRT(AYER/F)
      ATRMS= ARMS(J)
      AXMP(J)= AXRMS
      AYMP(J)= AYRMS
   21 CONTINUE
```

CALCULATE THE TOTAL, X-AXIS, AND Y-AXIS RMS ERROR AT A PARTICULAR ANGLE OF ATTACK.

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```
      CALL AXIS(0.0,0.0,9HRMS ERROR,-9,5.0,0.0,0.,4.)
      CALL AXIS(0.0,0.0,23HANGLE OF ATTACK (UNITS),23,6.0,90.,0.,4.)
```

PLOTS X-AXIS STARTING AT (0.0,0.0) WITH THE TITLE RMS ERROR. THE ANNOTATION STARTS AT 0.0 AND INCREASES BY 4.0 PER INCH.
PLOTS Y-AXIS STARTING AT (0.0,0.0) WITH THE TITLE ANGLE OF ATTACK (UNITS). THE ANNOTATION STARTS AT 0.0 AND INCREASES BY 4.0 PER INCH.

```
      CALL SYMBOL(0.0,6.5,0.1,10HFLIGHT NO.,0.0,10)
      CALL NUMBER(1.1,6.5,0.1,FLT,0.0,-1)
      CALL SYMBOL(0.0,6.25,0.1,11HFLIGHT DATE,0.0,11)
      CALL NUMBER(1.2,6.25,0.1,DAT,0.0,-1)
      CALL SYMBOL(3.25,6.50,0.1,14HCAMERA MAG NO.,0.0,14)
      CALL NUMBER(4.6,6.5,0.1,CAM,0.0,-1)
      CALL SYMBOL(3.25,6.25,0.1,9HBURST NO.,0.0,9)
      CALL NUMBER(4.25,6.25,0.1,BUR,0.0,-1)
```

PRINTS OUT LEGEND AT TOP OF PAGE.

```
      CALL SYMBOL(-0.5,-1.5,0.15,6HFIGURE,0.0,6)
      CALL SYMBOL(1.2,-1.5,0.15,24HERROR VS ANGLE OF ATTACK,0.0,24)
```

PRINTS OUT TITLE AT THE BOTTOM OF PAGE.

```
      DO 26  J=1,23
      AEF(J)=ARMS(J)/4.0
      AXEF(J)=AXMP(J)/4.0
      AYEF(J)=AYMP(J)/4.0
      AP(J)= ALP(J)/4.0
```

SCALES VALUES OF ERROR FOR PLOTTING.

```
      CALL PLOT(AEF(J),AP(J),3)
      CALL SYMBOL(AEF(J),AP(J),0.1,14,0.0,-1)
      CALL PLOT(AXEF(J),AP(J),3)
      CALL SYMBOL(AXEF(J),AP(J),0.1,0,0.0,-1)
      CALL PLOT(AYEF(J),AP(J),3)
      CALL SYMBOL(AYEF(J),AP(J),0.1,2,0.0,-1)
   26 CONTINUE
```

PLOTS X, Y AND TOTAL ERROR VERSUS ANGLE OF ATTACK.

```
      CALL PLOT(8.0,-0.5,-3)
      SEC=PTS(INDEX)/FPS
      SECP=SEC/4.0
      CALL AXIS(0.0,0.0,10HTIME (SEC),-10,SECP,0.0,0.0,4.0)
```

SETS UP REFERENCE FOR NEXT PLOT.
CALCULATES NUMBER OF SECONDS IN A PARTICULAR RUN.
SCALE SECONDS FOR PLOTTING.
PLOT X-AXIS STARTING AT (0.0,0.0) WITH TITLE TIME(SEC). THE ANNOTATION STARTS AT 0.0 AND INCREASES BY 4.0 PER INCH FOR AS MANY SECONDS AS WAS CALCULATED PREVIOUSLY

FIGURE 23 (CONTINUED)

```
      CALL AXIS(0.0,0.0,9HTOT ERROR,9,1.0,90.0,0.0,20.)
      CALL AXIS(0.0,2.0,10HHORZ ERROR,10,2.0,90.0,-20.,20.)
      CALL AXIS(0.0,5.0,10HVERT ERROR,10,2.0,90.0,-20.,20.)
      CALL SYMBOL(0.0,7.5,0.1,10HFLIGHT NO.,0.0,10)
      CALL NUMBER(1.6,7.5,0.1,FLT,0.0,-1)
      CALL SYMBOL(0.0,7.25,0.1,11HFLIGHT DATE,0.0,11)
      CALL NUMBER(1.6,7.25,0.1,DAT,0.0,-1)
      CALL SYMBOL(3.25,7.5,0.1,14HCAMERA MAG NO.,0.0,14)
      CALL NUMBER(4.6,7.5,0.1,CAM,0.0,-1)
      CALL SYMBOL(3.25,7.25,0.1,9HBURST NO.,0.0,9)
      CALL NUMBER(4.25,7.25,0.1,BUR,0.0,-1)
      CALL PLOT(0.0,3.0,3)
      CALL PLOT(SECP,3.0,2)
      CALL PLOT(0.0,6.0,3)
      CALL PLOT(SECP,6.0,2)
      CALL SYMBOL(-0.5,-1.25,0.15,6HFIGURE,0.0,6)
      CALL SYMBOL(1.2,-1.25,0.15,18HERROR TIME HISTORY,0.0,18)
      DO 30  I=1,INDEX
      TIME(I)=(PTS(I)/FPS)/4.0
      TOTER(I)=Z(I)/20.0
      HORER(I)= X(I)*(-1.0)/20.0 + 3.0
      VERER(I)= Y(I)*(-1.0)/20.0 + 6.0
   30 CONTINUE
      I= 1
      CALL PLOT(TIME(I),TOTER(I),3)
      DO 31  I= 2,INDEX
   31 CALL PLOT(TIME(I),TOTER(I),2)
      I= 1
      CALL PLOT(TIME(I),HORER(I),3)
      DO 32  I= 2,INDEX
   32 CALL PLOT(TIME(I),HORER(I),2)
      I= 1
      CALL PLOT(TIME(I),VERER(I),3)
      DO 33  I=2,INDEX
   33 CALL PLOT(TIME(I),VERER(I),2)
      Q= 0.0
      HI=1.5
      ALX2= 0.0
      DO 124  I= 1,INDEX
      ALX1= AL(I)
      IF(ALX1 .EQ. ALX2) GO TO 124
      IF(ALX1 .EQ. 0.0) GO TO 124
      TU= (PTS(I)/FPS)/4.0
      CALL NUMBER(TU,HI,0.075,ALX1,0.0,3)
      HI= HI-0.15
      Q= Q+1.0
      IF(Q .EQ. 3.0) GO TO 8
      GO TO 124
    8 HI= 1.5
      Q= 0.0
  124 ALX2= ALX1
```

PLOTS Y-AXIS STARTING AT (0.0,0.0) WITH TITLE TOTAL ERROR. THE ANNOTATION STARTS AT 0.0 AND INCREASES BY 20.0 PER INCH.

PLOTS Y-AXIS STARTING AT (0.0,2.0) WITH TITLE HORZ ERROR. THE ANNOTATION STARTS AT -20.0 AND INCREASES BY 20. PER INCH.

PLOTS Y-AXIS STARTING AT (0.0,5.0) WITH TITLE VERT ERROR. THE ANNOTATION STARTS AT -20.0 AND INCREASES BY 20.0 PER INCH.

PRINTS LEGEND AT TOP OF PAGE.

PLOTS X-AXIS FOR BOTH HORZ AND VERT ERROR.

PRINTS TITLE AT BOTTOM OF PAGE.

LOOPS THROUGH ALL POINTS FOR PLOTTING.

SCALES TOTAL, HORIZONTAL, AND VERTICAL ERROR AND TIME FOR PLOTTING.

THREE DO LOOPS TO PLOT TOTAL, HORIZONTAL, AND VERTICAL ERROR VERSUS TIME.

DETERMINES THE VALUE OF ANGLE OF ATTACK EACH TIME THE VALUE CHANGES AND PRINTS THIS NEW VALUE AT THE TIME WHEN IT CHANGED ON THE TIME HISTORY PLOT(PLOT 4).

FIGURE 23 (CONTINUED)

CALL PLOT(20.0,1.0,-3)	SET NEW REFERENCE FOR NEXT PLOT.
DO 27 I=1,INDEX X(I)=ABS(XX(I)/CON) Y(I)=ABS(YY(I)/CON) 27 CONTINUE	CONVERTS VALUES OF X AND Y PIPPER POSITION FROM COUNTS TO MILS AND TAKES THEIR ABSOLUTE VALUE.
28 TA=INDEX TT= TA/FPS DO 60 M=1,20 ROE(M)= M ROEX(M)= ROE(M)/4.0 BULEY= 0.0 DO 61 I=1,INDEX IF(X(I).GT. ROE(M)) GO TO 61 BULEY= BULEY + 1.0 61 CONTINUE PERCT(M)=(BULEY/TA)*100.0 PERCX(M)=PERCT(M)/20.0 60 CONTINUE	CALCULATES THE PERCENTAGE OF TRACKING TIME THAT CORRESPONDS TO A PARTICULAR PIPPER ERROR IN THE X-AXIS.
DO 62 M=1,20 ROE(M)= M ROEY(M)=ROE(M)/4.0 BULEY=0.0 DO 63 I=1,INDEX IF(Y(I).GT.ROE(M)) GO TO 63 BULEY = BULEY + 1.0 63 CONTINUE PERCT(M)=(BULEY/TA)*100.0 PERCY(M)=PERCT(M)/20.0 62 CONTINUE	CALCULATES THE PERCENTAGE OF TRACKING TIME THAT CORRESPONDS TO A PARTICULAR PIPPER ERROR IN THE Y-AXIS.
CALL AXIS(0.0,0.0,12HERROR(MILS) ,-12,5.0,0.0,0.0,4.0)	PLOTS X-AXIS STARTING AT (0.0,0.0) WITH THE TITLE ERROR(MILS). THE ANNOTATION STARTS AT 0.0 AND INCREASES BY 4.0 PER INCH.
CALL AXIS(0.0,0.0,24HPERCENT OF TRACKING TIME,24,5.,90.,0.,20.)	PLOTS Y-AXIS STARTING AT (0.0,0.0) WITH THE TITLE PERCENT OF TRACKING TIME. THE ANNOTATION STARTS AT 0.0 AND INCREASES BY 20.0 PER INCH.
CALL SYMBOL (0.0,5.75,0.1,18HSCORED AT F/S,0.0,18) CALL NUMBER (1.00,5.75,0.1,FPS,0.0,-1) CALL SYMBOL (0.0,5.5,0.1,10HFLIGHT NO.,0.0,10) CALL NUMBER (1.1,5.5,0.1,FLT,0.0,-1) CALL SYMBOL (0.0,5.25,0.1,11HFLIGHT DATE,0.0,11) CALL NUMBER (1.1,5.25,0.1,DAT,5.0,-1) CALL SYMBOL (3.25,5.5,0.1,14HCAMERA MAG NO.,0.0,14) CALL NUMBER (4.6,5.5,0.1,CAM,0.0,-1) CALL SYMBOL (3.25,5.25,0.1,9HBURST NO.,0.0,9) CALL NUMBER (4.25,5.25,0.1,BUR,0.0,-1)	PLOTS LEGEND AT TOP OF PAGE.
CALL SYMBOL(-0.5,-1.5,0.15,6HFIGURE,0.0,6) M=1	PLOTS TITLE AT BOTTOM OF PAGE.

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

FIGURE 23 (CONCLUDED)

```
      CALL PLOT(ROEX(M),PERCX(M),3)
      DO 64 M=2,20
      CALL PLOT(ROEX(M),PERCX(M ),2)
   64 CALL SYMBOL(ROEX(M),PERCX(M),0.1,0,0.0,-1)
      M=1
      CALL PLOT(ROEY(M ),PERCY(M),3)
      DO 65 M=2,20
      CALL PLOT(ROEY(M),PERCY(M),2)
   65 CALL SYMBOL(ROEY(M),PERCY(M),0.1,2,0.0,-1)
      CALL SYMBOL(3.75,0.75,0.1,0,0.0,-1)
      CALL SYMBOL(3.75,0.5,0.1,2,0.0,-1)
      CALL SYMBOL(4.0,0.75,0.1,7HLATERAL,0.0,7)
      CALL SYMBOL(4.0,0.5,0.1,12HLONGITUDINAL,0.0,12)
      CALL PLOT(8.0,0.0,-3)
      WRITE(6,720)FLT,CAM,BUR
  720 FORMAT(1H1,6HFLIGHT,4X,F4.0,4X,10HCAMERA MAG.,4X,F4.0,
     C4X,5HBURST,4X,F4.0)
      WRITE(6,700)
  700 FORMAT(//////15H TIME ON TARGET,10X,10HSTART TIME)
      DO 810   I=1,INDEX
  801 IF(Z(I).GT.HR) GO TO 803
  802 BOOM=BOOM + 1.0
      GO TO 810
  803 IF(BOOM.GT.0.0) GO TO 804
      GO TO 807
  804 IF(BOOM.GT.RING) GO TO 805
      GO TO 807
  805 L=L + 1
      N= BOOM
      TX(L)= PTS(I-N)/FPS
  806 TISCO(L)=BOOM/FPS
      WRITE(6,701) TISCO(L),TX(L)
  701 FORMAT(1H ,6X,F4.1,19X,F4.1)
      CAP=CAP + TISCO(L)
  807 BOOM= 0.0
  810 CONTINUE
      IF(L.EQ.0)GO TO 704
      R=L
      AVTIME= CAP/R
  704 WRITE(6,702)
  702 FORMAT(//////13H AVERAGE TIME)
      WRITE(6,703) AVTIME
  703 FORMAT(1H ,6X,F4.1)
      GO TO 200
      END
```

PLOTS LATERAL ERROR VERSUS PERCENTAGE OF TRACKING TIME.

PLOTS LONGITUDINAL ERROR VERSUS PERCENTAGE OF TRACKING TIME.

PRINTS LEGEND TO TELL WHICH LINE ON PLOT IS WHICH.

TELLS PLOTTER TO MOVE 20.0 INCHES TO THE RIGHT AND 1.0 INCHES UP AND ESTABLISH A NEW REFERENCE POINT.

LOOP THROUGH ALL POINTS TO CALCULATE TIME IN HIT RING.
DECIDES WHETHER POINT IS WITHIN HIT RING. IF IT IS NOT, SKIPS TO STATEMENT 803.
TOTALS UP NUMBER OF CONSECUTIVE POINTS IN HIT RING.
IF THE VALUE OF LINE 216 IS GREATER THAN ZERO, SKIP TO STATEMENT 804.
RING IS A PREDETERMINED NUMBER WHICH REPRESENTS THE NUMBER OF CONSECUTIVE POINTS THAT HAVE TO BE IN THE HIT RING IN ORDER TO BE CONSIDERED A HIT. IF THE NUMBER OF CONSECUTIVE POINTS(LINE 216) IS GREATER THAN THE PREDETERMINED VALUE, SKIP TO STATEMENT 805.
IF NOT, SKIP TO STATEMENT 807.
DETERMINES THE NUMBER OF TIMES THROUGH THIS PORTION OF THE LOOP.
CHANGES FIXED POINT NUMBERS TO FLOATING POINT NUMBERS.
CALCULATES THE TIME AT WHICH THE SPECIFIC RUN STARTED.
CALCULATES THE TOTAL TIME IN WHICH THE POINTS WERE WITHIN THE HIT RING.

TOTALS UP ALL THE TIMES IN THE HIT RING.
RESETS VALUE TO ZERO FOR NEXT TIME THROUGH LOOP.

CHECK TO SEE IF VALUE IS ZERO.
CHANGE FIXED POINT NUMBERS TO FLOATING POINT NUMBERS.
CALCULATES AVERAGE TIME IN HIT RING.

RETURNS TO BEGINNING OF PROGRAM FOR NEXT RUN.

FLIGHT 71. CAMERA RUN 2. BURST 1.

TIME ON TARGET	START TIME
.8	8.2
.8	9.5
1.0	10.5

AVERAGE TIME
.9

FIGURE 24 PLOTTER PROGRAM PRINTOUT

LIST OF ABBREVIATIONS AND SYMBOLS

Item	Definition	Units
CAS	control augmentation system	- - -
cg	center of gravity	percent
DEG	degraded	- - -
DIS	disengaged (unaugmented)	- - -
FPS	frames per second	- - -
G, g	normal acceleration	- - -
GAC	good aircraft	- - -
KIAS	knots indicated airspeed	knots
KTAS	knots true airspeed	knots
L	longitudinal axis	- - -
L-D	lateral-directional	- - -
LONG	longitudinal	- - -
MSL	mean sea level	- - -
P	pitch	- - -
PR	pilot rating	- - -
$\bar{q}$	dynamic pressure	psf
R	roll	- - -
RMS	root mean square	- - -
s	LaPlace operator	- - -
S/N	serial number	- - -
Y	yaw	- - -
α	angle of attack	units or degrees